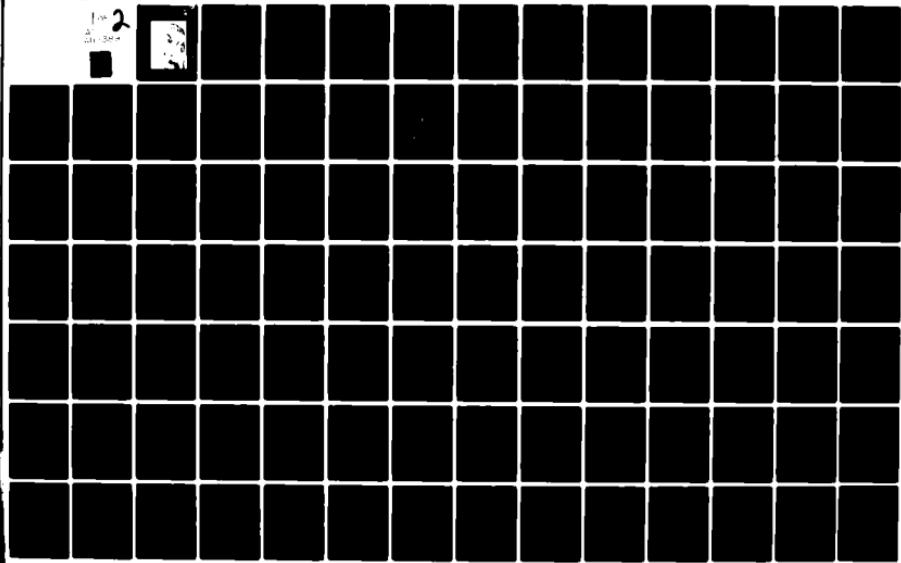


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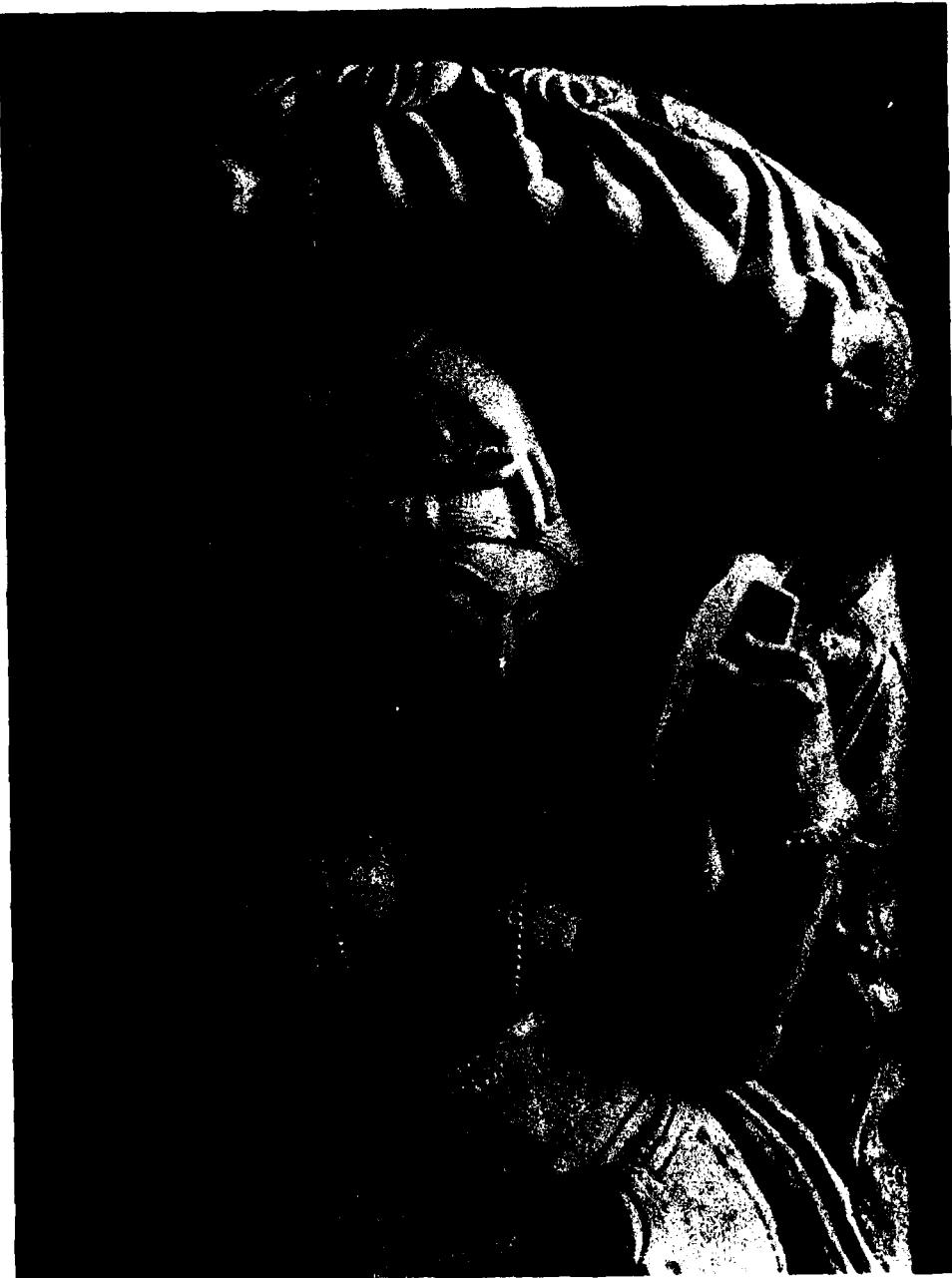
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Very large scale integrated circuits (VLSI)	Biological molecules
Laser-induced processes	Macromolecule
Laser-induced fluorescence measurement	Non-Von Neuman architecture

20. Abstract (cont.)

with certain reports also being contributed by visiting stateside scientists. Occasionally a regional scientist will be invited to submit an article covering his own work, considered to be of special interest.

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Cover: An 11th century Indian sculpture, from the Indian city and state, Bhuvaneshvara, Orissa, entitled, "Girl Looking into Mirror." It is reproduced from the collection of the office of Cultural Affairs, the Indian Embassy, Tokyo, Japan.

A GLIMPSE AT JAPAN'S DEVELOPMENT OF SOFTWARE ENGINEERING TECHNOLOGY IN 1981

K. H. Kim

INTRODUCTION

In September 1981, the author visited a total of ten Japanese organizations engaged in research and development (R&D) in the area of software engineering. This survey has left the author with an impression that the United States still maintains the position of the most advanced country in the software engineering field, but Japan is catching up in highly cost effective ways. Some of the major trends noticed in Japan are:

- focus on testing and integration of various concepts and approaches originated from the United States and Europe,
- considerable investment in development of coherent sets of software tools, and
- rapid advances in real time software technology and basic artificial intelligence technology.

Japan is currently trying to extend its previous successful experiences in technology buildup via national R&D projects (e.g., computer hardware technology) to the software technology area. The new national R&D project which is intended to push Japan to the forefront of the computer system technology by 1990, is called the Fifth Generation Computer System (FGCS) project and will last for ten years starting in 1982. The Japanese government plans to pour some \$45 million into the FGCS project during the first three years (82-84), and there are indications that the total project cost might reach several hundred million dollars. The project will involve talents from all three R&D circles, government, industries, and universities. Artificial intelligence, software engineering, non-Von Neumann architecture, and VLSI are the key technologies to be dealt with in the project. A great deal of attention is being paid to the man-machine interface. Also, research works on software engineering and artificial intelligence are intertwined in the project in order to deal with the total system (i.e., user, machine, environment) in a cost effective way. Several factors such as the positive results of previous national R&D projects, the strong VLSI capability built up, and the vision displayed in the project plan, make it difficult for computer R&D circles in the United States to take Japan's ambitious move lightly. (Editor's note: An in-depth report on the Fifth Generation Computer System will appear in the next issue of the *Scientific Bulletin*).

During the nine days stay in Japan, the author visited a total of ten organizations engaged in research and development (R&D) in the area of software engineering. Three of the organizations visited are government operated and supervised organizations, four of them industrial laboratories and three of them universities. They are the following:

- Government operated and supervised organizations:

Information-technology Promotion Agency (IPA)
[belonging to the Ministry of International Trade and Industry (MITI)]

Electrotechnical Laboratory (ETL)
[belonging to MITI]

Yokosuka Electrical Communication Laboratory (ECL)
[belonging to Nippon Telegraph and Telephone Public Corporation (NTT)]

- Private industry R&D laboratories:

Fujitsu Laboratories Ltd., Software Laboratory

Hitachi Software Engineering Company, Ltd.

Nippon Electric Co., Ltd., Software Product Engineering Laboratory

Toshiba Fuchu Works, Software Factory

- Universities:

Keio University

University of Tokyo

Tokyo Institute of Technology

The nearly equal division of the visiting time among the three types of organizations (i.e. government, industry, and universities) was this author's decision. However, the selection of the ten organizations that were visited and the arrangement for the visits were the kind work of Professor Hideo Aiso at Keio University, a distinguished leader in computer science research in Japan. There are many organizations in Japan where software engineering research is active. After the trip, this author became fully convinced that the ten organizations visited were about the best combination that anyone could select for the purpose of a nine day survey of Japan's development of software engineering technology.

Nevertheless, what this author saw must be labeled as "the tip of the iceberg." That is primarily because the duration of each site visit was seldom greater than a half day. This limitation made it possible to observe only a small portion of the relevant activities at each organization. Some organizations, especially the industrial organizations, had slide presentations that summarized their activities, thereby allowing this author to gather somewhat more information than at other organizations. Two graduate students working under Professor Aiso accompanied the author throughout the visit. They provided efficient travel guidance and served as interpreters occasionally.

BACKGROUND

TIMING OF THE SURVEY

Through the 1960s software cost emerged as a dominant factor in determining a computer system's costs. The cost of software in industrialized countries increased so rapidly that in the late '60s the term "software crisis" was coined. This trend continued into the '70s while an increasing amount of R&D effort was poured into advancing software engineering technology. One estimate says that today companies spend over \$10 billion on external software expenditures and the software industry will become a \$38 billion industry by 1986. Yet today's software industry in the United States suffers tremendously from the problems of insufficient reliability and poor maintainability of software products, frequent development cost overrun, and a high personnel turnover rate.

On the other hand, Japan is known to have achieved phenomenal advances in all segments of technology through the '60s and '70s. High productivity of Japanese labor and good quality control by Japanese companies have become pet topics of many industrial analysts. It is natural that people have begun asking if Japan's technological advances will also surpass the United States in the computer field which has so far been known to be one of the few areas where the United States has maintained a technological edge. There is mounting evidence that Japan's computer hardware technology is already on a par with that of the United States. Also, a report by the Japanese government indicates that in 1980 Japanese computer companies and semiconductor companies have become \$5 billion industries.

Given these circumstances, it was to be assumed that significant activities would be evident in Japan's software R&D circles at the time of this author's visit. Indeed there were noticeable efforts. However, this is not to say that the United States technological edge in software engineering has eroded by any measure.

MAJOR SOFTWARE TECHNOLOGY R&D GROUPS IN JAPAN

A brief explanation is in order about the relative positions of the ten visited organizations in software technology R&D circles in Japan.

- Government operated and supervised organizations

Information-technology Promotion Agency (IPA)

This agency, belonging to the Ministry of International Trade and Industry (MITI), was created in 1970 to promote and aid software development and utilization. It is the major government agency subsidizing the costs of developing promising software by the software industry. In 1980, it gave contracts worth \$14 million to the software industry.

Yokosuka Electrical Communication Laboratory (ECL)

This is one of the three R&D laboratories in the Nippon Telegraph and Telephone Public Corporation (NTT) which plays a role similar to that of ATT in the United States. The main area of research in this laboratory is data communication networks including video communication and input-output equipment. LSI and switching technology are covered in the other two laboratories. There are eight R&D divisions in the Yokosuka ECL. The author met with members of the staff in the Data Communication Development and Data Processing Development divisions.

Electrotechnical Laboratory (ETL)

This is the main and largest government-operated research laboratory covering the area of electronics and information processing technologies. This laboratory was created in 1891 as an electrical engineering laboratory. However, its current structure which emphasizes electronics and information processing fields was established in 1970. In the year 1980, the number of staff researchers was 572, and the operating budget was \$50 million. The main efforts in the laboratory have been long-term national R&D and advanced research projects. There are thirteen R&D divisions in ETL. The author interacted with the staff of the Computer Science Division.

- Private industry organization

Fujitsu Laboratories Ltd.

Fujitsu Limited is the largest computer manufacturer in Japan and produces large-scale general purpose computers which compete with the large IBM computers. Fujitsu Laboratories Limited is the research arm of Fujitsu Limited and has eight R&D divisions including the Computer Systems Division. The Computer Systems Division has four laboratories. The author was also briefed by a staff member in the Software Division of Fujitsu Limited about several on-going projects in that development division.

Hitachi Software Engineering Company, Ltd. (Hitachi SK)

Hitachi Ltd. is an electric machinery manufacturer and has, under its control, 41 consolidated subsidiaries including Hitachi SK. Hitachi is the second largest computer manufacturer in Japan and produces large-scale general purpose computers competing with large IBM computers. At the time of this author's visit, Hitachi SK employed over 1,200 programmers. Hitachi SK had net sales of \$46.3 million in the year 1980. This amount of sales was the largest among Japanese companies specializing in software production.

Nippon Electric Company (NEC)

NEC is mainly a telecommunications equipment manufacturer and is the largest vendor of equipment for Nippon Telegraph and Telephone Public Corporation (NTT). NEC's computer business is the third largest in Japan. NEC's main computer products are not IBM-compatible. The R&D group within the company consists of five research laboratories. The Software Products Engineering Laboratory is one of the five and is the one that this author visited. Its main activity is the development of software engineering methodologies and tools.

Toshiba Fuchu Works

Toshiba Electric Company is an electric machinery manufacturer and its computer business is smaller than Fujitsu, Hitachi, and NEC, but close in size to Mitsubishi Electric Corporation and Oki Electric Company. Toshiba Fuchu Works is one of the major plants of Toshiba and has, among other things, a software factory where various real time computer control systems are manufactured. The software factory has 2,000 software development employees divided among various departments specializing in different real time applications. The author interacted with the staff of the software factory.

- Universities

Keio University

Keio University is an 125 year old private university with 25,000 students. It is regarded as one of the two highest quality private universities in Japan. The Electrical Engineering Department at Keio University has 36 faculty members. The author visited the Computer Engineering group in the department. The group was headed by Professor Hideo Aiso who had previously participated in the national R&D project aimed at producing computers that would surpass the IBM 370 in performance and had designed the first computer that met this goal (manufactured by Hitachi).

Tokyo University

Tokyo University is a public university and is known as the most prestigious university in Japan. The author visited a faculty member in the Department of Mathematical Engineering and another in the Department of Information Science, both of whom are engaged in research on software engineering.

Tokyo Institute of Technology

Tokyo Institute of Technology is a major public university in Japan with emphasis on applied science and engineering. The Department of Information Science is one of the first five information processing oriented departments established in Japanese government-supported universities. The department has three sections, one of which is the Computer Science Section. In addition, the Department of Computer Science also covers software areas. The author visited two faculty members in the Department of Information Science and a faculty member in the Department of Computer Science, all of whom were engaged in research on software engineering.

OBSERVATIONS

GOVERNMENT OPERATED AND SUPERVISED ORGANIZATIONS

The main function of the Information-technology Promotion Agency (IPA) is to help Japan's software industry to capture a bigger share of the foreign software market. Although its activities which have an impact on the software engineering technology in Japan are numerous, two activities are particularly worth noting. One is the Software Production Technology Development Project, which was assigned to the Joint System Development Center (JSD). JSD is an organization founded in 1976 under the guidance of the Ministry of International Trade and Industry (MITI) by seventeen leading software firms. IPA provided \$5 million in 1978 and \$7 million in 1979 for the project. The project goal was to establish a library of basic modules from which any application program can be generated. The author did not have a chance to visit JSD and did not obtain detailed information about the project. The basic modules are apparently written in a PL/I type programming language. The project has been completed, but the author has not heard about its success or failure.

The other interesting activity is the establishment of the Software Technology Development Center (STDC) in 1981 by IPA. STDC is an open laboratory which provides hardware, laboratory space, and funds for personnel of those software companies willing to develop new software.

Yokosuka ECL is carrying out extensive developmental research on the Data Communication Network Architecture (DCNA) and NTT's standard information processing system (DIPS: Dendenkoshia Information Processing System). Some of the other interesting products being developed include video-conferencing systems and facsimile-based text editing systems. An illustration of the capability of the latter system is given in Figure 1. The techniques used for the various systems being developed, e.g., techniques used in development of DIPS software, appear to be at the level of the current state of the art in software engineering. However, ECL personnel seem to have been more diligent, if not more successful, in utilizing software engineering tools than many software development groups in the United States. For example, two software tools, Test Path Analysis Program and Control Scope Analysis Program, are listed as the major technologies applied to the testing phase of the DIPS software development. In fact, the Processing Programs Section

at ECL is engaged in R&D of various new software tools. To illustrate the types of tools under development, a few are listed below.

- PAVES (Program Analysis, Validation and Evaluation System)

PAVES provides a quantitative measure of tested routes, enabling efficient exhaustive test.

- CHASE (Check and Analysis System for program Errors)

CHASE facilitates program error analysis utilizing the program data base generated by PAVES. Its main functions are: automatic check-out of data attribute errors, and symbolic debugging.

- ADVISER (Automatic Document Version Improving System for Easy Revising)

ADVISER generates maintenance documents for system programs by extracting information from the self-contained source code.

- PAL (Program Automation Language)

PAL is a system design language that automatically generates an executable program from a description of its data structure specifications.

- GUIDE (General User Interface System with Dialogue Entrance)

GUIDE provides an intelligent and general terminal users interface for various end user languages. It recognizes questions in formal or natural Japanese. It handles graphics and voice as well as characters. It contains dialogue and guidance facilities for specific regions.

- PROTO-E (Programming Tool--Extensible language)

PROTO-E is an extensible language designed for automatic generation of problem oriented languages and language converters.

- QUICK (The management system for Quality Information, process Checking and Know-how of software development)

QUICK is a total management support system for software development.

Most of these tools exist at ECL in prototype forms. Like most major computer manufacturers, they have also extended high level languages such as FORTRAN, COBOL, and PL/I with Kana (Japanese alphabet) variable names and comments.

The atmosphere at the Electrotechnical Laboratory (ETL) is more that of basic research than at Yokosuka ECL, although much of the research at ETL is still very pragmatic. The staff at ETL are looking far into the future. The author has the impression that ETL staff members have played a key role in creating and moving the Fifth Generation Computer System project (in short, the FGCS project), which is a national R&D effort. They are well aware of new concepts and techniques discussed, but not much tested in the United States and Europe. Their common research strategy seemed to be to identify the advantages of the many approaches developed in the United States and Europe and to

then combine them into a new approach. For example, the HISP (Hierarchical structured Specifications and Programs processor) project is aimed at combining the theoretical work of algebraic specification with the practical work of Jackson's design methodology. Another example is the Intelligent Data Base System (IDBS) project which is aimed at adding methods of human intelligence such as deduction and understanding to relational data base management systems, thereby substantially improving the man-machine interface in question answering. Although the author did not detect any radical concepts and techniques produced at ETL, and for that matter other Japanese organizations (possibly due to the author's oversight), their way of testing new concepts (originating from the United States and Europe) looked quite cost effective and there were many original components in their application research efforts based on the new concepts. In particular, all the efforts at ETL have been aimed at producing tangible products useful to end users in practical fields although their goals were a little more risky than those of the projects under way in private industry. For example, the Multi-Display Terminals project is aimed at utilizing multiple display terminals to support one programmer by making multiple documents related to the same program, e.g., program specification, source listing, program profile, etc., visible to the programmer. Multiple terminals would behave like one sophisticated terminal.

ETL also played the key role in the Pattern Information Processing System (PIPS) project which was carried out during the 1971-1980 time frame at a cost of \$105 million. ETL not only conducted basic studies, but also played the role of the technical coordinator and supervisor of this national R&D project in which many industrial organizations participated through development contracts. It appears that this artificial intelligence research project has had a very positive impact on all segments of Japan's computer technology. The author feels that Japan is now at the forefront of the technological fields such as image processing devices and materials, pattern recognition techniques for both visual and audio patterns, parallel and associative processing architectures, and inference and learning techniques.

At present, the new insights into artificial intelligence obtained through this PIPS project seem to be strongly guiding the direction that the national R&D project for the 1980s, i.e., the FGCS project, is taking.

PRIVATE INDUSTRY R&D ORGANIZATIONS

The competition among major computer companies in Japan is fierce. Although the author saw different pieces of R&D work at different companies it would be a safe guess that a complete set of R&D efforts corresponding to all those different pieces put together could be found at any of the companies. One obvious common effort that could be seen in all the companies visited was the sizable investment in the development of a coherent set of software engineering tools.

R&D efforts at Fujitsu Laboratories, Ltd., are a mixture of short-term and long-term projects. The short-term projects are mainly oriented to the development of software tools that will be used in the near future (i.e., five-six years or earlier). The PDAS (Programming and Design Assist System) project is in this category. It is aimed at developing a package of software tools supporting module specification, checkout by simulation, program synthesis using generic program components, and documentation. Actually, Fujitsu developed the first version of SDSS (Software Development Support System) in 1978 and the version contained project library subsystem, MDL (Module Description Language), MDA (Modulae Description Analysis), and several test support tools. PDAS will probably become a supplement to SDSS. Also, under way at Fujitsu

Laboratories is an effort to move Bell Laboratories' UNIX-version seven operating system onto an Intel 8086-based microcomputer. Another tool under development is a CAD (Computer-aided Design) system supporting register-transfer level design and subsequent generation of logic circuits. On the long-term project side, there is a project on machine translation of Japanese into English. A demonstration output is shown in Figure 2. They say that the first application of this translator will be in translating computer manuals written in Japanese into English versions. This is considered reasonable. Incidentally, the author heard of a number of places where Japanese-to-English translation by machine was being studied but none where English-to-Japanese translation by machine was being studied. The author also heard during this trip that two reasons why American-produced personal computers such as TRS-80 and Apple are not so popular in Japan might be the insufficient Japanese documentation and the lack of Japanese input-output capability. Another long-term project under way is a natural language programming project. The project is motivated by the shortage of programmers which will get worse in the 1980s. It is aimed at developing an intelligent system which will maintain the initiative in generating a program through a natural language dialogue with the user who may not be a programming specialist. For example, a dialogue would proceed as follows:

Q: Choose one of the following:

1. Making a new program.
2. Modification of an old program
3. Execution of a program

A: Two

Q: What do you call the new program?

A: SALES-REPORT

Q: What does SALES-REPORT do?

A: Merges two files. One of them is the sales of Osaka office in August and the other is...

The concept here seems to be quite advanced and the direction is considered to be proper. Not much detail was made known to the author. They said that a small pilot system was under development. By nature of their main business, Fujitsu is heavily engaged in development of general purpose operating systems. For example, their OS IV/F4 operating system running on their machine FACOM M200 is apparently compatible with IBM OS/MVS and the total package consists of 15 million instructions. It appeared that their emphasis in development was in the areas of distributed processing systems, relational data bases, distributed data bases, and multicomputer systems. It is suspected that these development efforts are along the same line as the developments by IBM and other major mainframe manufacturers in the United States. As a passing note, the author would like to mention a word heard from a government employee that a Fujitsu subsidiary, which is the largest producer of numerical control machinery in the world, has developed robots that produce other industrial robots (for painting, assembling, etc.).

Hitachi Software Engineering Company, Ltd. (Hitachi SK) left this author with a strong impression of their software tool development. In fact, when the author visited, they had just exported two major software tools to the United States, HIDOC (Hierarchical Documentation Writer) and SHC (Shorthand Cobol). Their application software

development is mostly Cobol-based. HIDOC is a Cobol postprocessor which analyzes submitted Cobol programs and produces a series of charts that clearly show the program structure at several different levels as well as other documents. Its output is thus useful for program debugging and maintenance. Incidentally, HIDOC was developed with IPA funds. Another software tool that they are contemplating for export is STAMPS (Standardized Modular Programming System). STAMPS is advertised as an easy-to-use, semiparametric, and business-oriented language processor which generates Cobol source programs. Hitachi SK's SPST (Software Production Support System) is a carefully integrated, coherent set of software tools. HIDOC, STAMPS, and other tools are integral components of SPST. Some of the components are under development. Hitachi SK's interesting projection of software productivity increase is shown in Figure 3.

Other noteworthy efforts at Hitachi SK in the area of software engineering include a study of software requirements "patternization" techniques and expertise accumulating techniques. The study on requirements patternization is aimed at techniques for classification and modeling of the software to be developed in order to effectively utilize previous software development experiences. The study on expertise accumulating is concerned with the buildup of good project diaries and system components which can be reused in the future. Another interesting effort is the personal computer project aimed at developing interactive Cobol programming tools running on small machines for home programmers. This project is motivated by the ever-worsening shortage of programmers and the possibility of utilizing housewives for program development.

Nippon Electric Company Ltd., (NEC) is also developing a coherent set of software tools called SDMS (Software Development and Maintenance System). SDMS consists of five subsystems: design subsystem, programming subsystem, test subsystem, project management subsystem, and product management subsystem (performing automatic version control and managing job control command lists, test data used, etc.). A sample output of the design subsystem (a hardcopy obtained from a graphics terminal) is shown in Figure 4. NEC also developed STEPS (Standardized Technologies and Engineering for Programming Support) which contained 20 standard Cobol program modules. They were contemplating the exportation of STEPS at the time of the author's visit. An interesting project that has recently started at NEC is the development of a requirements engineering system. They are planning to develop requirements analysis tools, tabular form requirement specification languages, and tools aiding the generation of programs from the requirements specifications. Development of requirements engineering systems started in early '70s in the United States. The author obtained insufficient details on the NEC's development plan to assess their deviations from the works under way in the United States. For system software development, their primary programming language is a PL/I-dialect.

It appears that NEC has been making a considerable amount of investment in man-machine interfaces, especially in the speech recognition area. They say that some of their speech recognition products are used in several airport baggage handling systems. The R&D on office information system at NEC also seems to be progressing well. They are developing document-based office systems capable of handling not only character strings but also tables and graphs, etc. Incorporation of a voice recognition subsystem is in the plan. A project on special-purpose computers for image processing applications also came to the author's attention during the visit.

Toshiba Fuchu Works is different from the three other industry laboratories in one important respect: it specializes primarily in real time applications. There is another division of Toshiba, however, involved in commercial data processing applications. The laboratory at Toshiba Fuchu Works that the author visited is called the Software Factory.

The Software Factory is housed in three adjacent buildings: one designated for software design, another for software and hardware design, and the third for systems testing. Computers in the three buildings are connected over high speed buses to form computer networks (Figure 4). There are 200 terminals in the software design building. The systems to be delivered are tested in the system test building under a simulated plant environment. The software factory is equipped with SWB (Software Workbench) system which is a coherent and comprehensive set of software tools. SWB contains tools such as SADT, CASAD (Computer-Aided Specification Analysis and Documentation), HIPO, PROMISS (Program Information Management and Service System--to facilitate reuse of proven programs), SYSGEN (System Generator--to synthesize the needed software by using both newly coded modules and standard modules), etc. The first version of SWB was developed in 1977 and has been continuously evolving since then. At the Software Factory, 83% of the software is written in Real Time Fortran or PL/I, 11% in a machine-oriented system description language, and 6% in assembly languages. As shown in Figure 5, there has been an annual 14% increase in productivity in the Software Factory since 1976. In 1981, an average of 2,870 instructions were produced per month by an average programmer. They attribute this high productivity to the return of their investment in software tools and computer networks, reuse of modules validated through previous applications, and their software quality assurance plan. The author wonders if the Software Factory is not one of the most advanced real time software engineering organizations in the world.

There is one important software R&D activity that involves most of Japan's software industry. An association involving ten companies, called the Computer Basic Technology Research Association (CBTRA), was created in 1979 and will exist until 1983. The main goal of CBTRA is to elevate the level of Japan's software technology. CBTRA consists of two groups, one for R&D of the basic software technology and the other for the development of new peripheral equipment. The total R&D budget for the five years period is \$270 million of which 50% is a subsidy from the Japanese Government (MITI). The subjects of research of the basic software technology group include network management, data base management, and very high level languages among other subjects.

UNIVERSITIES

The research at Keio University touches upon all aspects of software engineering including both practical and theoretical areas. There is somewhat theoretically flavored research going on in the areas of formal specification, program verification, and functional programming. But there is also development-oriented work on new programming languages (including system programming languages), compilers, program optimization, simulation, and application-oriented computer architectures. It appears that Keio University researchers made early entries into the fields of distributed operating systems and local area networks. All these works are similar to the research now pursued at leading academic institutions in the United States.

It became clear during the trip that the interaction between universities and industries in Japan is generally less active than that in the United States. One of the distinct exceptions is Professor Hideo Aiso's group at Keio University. The group is engaged in joint research projects with all six major computer companies as well as with Yokosuka ECL. The group is also participating in the FGCS project. Professor Aiso's interpretation of the FGCS project was a test ground for the Japanese ability to create new computer system concepts. The group's research activities range over both system software and computer architecture. Their research in computer architecture is particularly advanced. They are trying to identify ways to reduce software engineering problems by providing new architectural support. For example, they have developed a

"debugging machine" (which is a computer adapted via dynamic microprogramming) to provide efficient support for program debugging activities. They are also studying the possibility of obtaining a high level language machine capable of efficient execution of Ada programs. Another study in this category is one on error-free machines, i.e., computers which do not create numerical errors. Apparently some of these ideas have been adopted in the FGCS project as research topics. Another interesting project that they were just formulating at the time of the author's visit was a project on "VLSI-zation" of software modules.

The people whom the author met at the University of Tokyo were engaged in research on programming languages (including artificial intelligence application programming languages and Ada), programming language-oriented editor, and architectural support for the software engineering processes. The research on programming languages is more oriented to the study of language processors and other tools for languages such as Lisp, Prolog, and Ada. The people at University of Tokyo were apparently very active in debugging the preliminary Ada specification. The research on architectural support is moving along the same line as the research at Keio University. There are software projects being conducted by other people at the university and the subjects range over distributed system software, data bases, word processors, and formula translation systems. Therefore, the research activities in the area of software engineering at University of Tokyo are similar to those at the leading academic institutions in the United States.

The people whom the author met at the Tokyo Institute of Technology (TIT) were engaged in research on programming languages, text processing, data bases, functional programming, and program specification. The work on programming languages produced an efficient processor of Clu, a language developed at Massachusetts Institute of Technology (MIT) in the United States, and an efficient processor of Snobol 3, a string manipulation language developed at Bell Telephone Laboratories in the United States. The work on text processing is mainly concerned with production of Japanese documents. An interesting approach being experimented with here is to use a sort of Romanized Japanese texts, i.e., Japanese text phonetically represented in Roman alphabets, as input and to print output texts in Japanese characters. In addition, a "microprogrammable" text editor which allows a user to dynamically define a command set, is under development. The work on data bases has focused on the subject of query processing. The work on functional programming touches on the issues of program verification, hierarchical structuring, and module decomposition. They have also initiated a study on functional programming for real time applications and are planning to apply functional programming to natural language processing. The work on program specification has involved a study of a logic-based approach as well as a study of a technique for specification of concurrent programs. The software research activities at Tokyo Institute of Technology (TIT) (with the exception of the work on Japanese document processing) are again similar to those at the academic institutions in the United States.

The author also had an opportunity to interact with a faculty member of Hiroshima University. The research work of his group is in the area of pattern recognition and special purpose computer architecture for pattern recognition applications. The work is as advanced as similar work going on in the United States.

CONCLUSION AND RECOMMENDATION

During this short survey, the author did not detect new fundamental concepts and approaches unheard of in the United States although this could be due to an oversight. Three major trends were noticed.

- Japanese software research is generally focused on testing and integration of various concepts and approaches originated from the United States and Europe. The researchers tend to keep abreast of new developments in a broad spectrum of computer science and engineering and to take views of overall systems.
- Most Japanese software research is practically oriented and aimed at producing tangible products useful to end users. Considerable emphasis is put on the development of coherent sets of software tools. They seem to have better success in finding users of the tools than tool developers in the United States.
- Real time software technology and basic artificial intelligence technology including pattern recognition are particularly advanced.

Based on the observations made during this trip, the author can in no way conclude that the United States has lost its technological edge in software engineering fields. The United States still makes considerably more investment in R&D of new software engineering technologies. Utilization of technologies may be a different matter, however. The approaches that Japan is using to catch up in software technology are highly cost effective. The Fifth Generation Computer System project is intended to put Japan to the forefront of computer technology by 1990. It is indeed an ambitious move by Japanese computer research circles and the spinoff of such a research effort can be substantial, even if the desired goals are not fully met.

What the author saw during the short survey does not justify any recommendation for a significant change in software technology R&D activities in the United States. However, the author has become more assured through the trip of the need in the United States for continued or increased emphasis in the following R&D areas:

- Technology integration. Many different types of software technologies have been developed and new technologies are continually appearing. Although many of those are not mutually exclusive, they remain unintegrated, thus receiving relatively poor acceptance from the people in the production field. Emphasis by Japanese R&D groups on integration of software tools into comprehensive software development systems as well as their plan to merge software engineering and artificial intelligence research in the FGCS project is something to think about.
- Continued emphasis on real time software engineering and basic artificial intelligence research.

These two areas have received considerable attention from R&D groups in the United States, especially DOD (Department of Defense) related groups. In the 1980s and onward, these technologies are expected to play important roles not only in the defense and space exploration fields but also in other industrial and commercial fields. Japan seems to be building up a strong technical base in the two areas.

- Joint R&D projects.

The interaction between industries and universities in research seems to be generally less active in Japan than in the United States. However, the Japanese government provides some opportunities via national R&D projects, such as the FGCS project and the supercomputer project, for cooperative research. In recent years, there has been a movement in the United States toward putting more emphasis on joint university-industry R&D efforts. This is a healthy move for the future of computer technology in the United

States and should be put into practice more effectively. The need for more effective implementation is evidenced by the current big gap between universities and industries in the techniques and approaches practiced as well as in the research topics of interest. Such a move can only help the United States maintain a technological edge in software engineering and other computer fields over the rest of the world.

ACKNOWLEDGEMENT

The author is very grateful to the Director and the staff of ONR Far East, and Professor Hideo Aiso of Keio University for their kind help in making arrangements for his visits to the ten R&D organizations in Japan. If the two graduate students working under Professor Aiso, Mr. Takefuji and Mr. Lee, had not guided the author, he would have been able to see only half of what he saw. Finally, the author would like to express deep gratitude for all those hard working people in Japan who generously provided their time and hospitality for the author.

* A Facsimile Based Text Editing

A text editing system by picture processing is being researched as an example of facsimile-based artificial intelligence services in the future.

By merely adding special marks to the original documents by

hand and inputting them into the facsimile terminal, the document text can be edited in accordance with the marks and the completed documents are obtained as facsimile outputs.

**BASED [FACSIMILE
TEXT EDITOR BY MARK
RECOGNITION** At first, five kinds of marks of handwritten in the original text are recognized **HANDWRITTEN** to make rearrangement list. Then, the copy of **[fair] the** text is made by rearranging the text according to the list. **[as dot patterns]**

**FACSIMILE BASED TEXT
EDITOR BY HANDWRITTEN
MARK RECOGNITION**
At first, five kinds of handwritten marks in the original text are recognized to make rearrangement list.
Then, the fair copy of the text is made by rearranging the text as dot patterns according to the list.

Original

Result

Figure 1. An illustration of the Yokosuka ECL's facsimile-based editor

P 1 1 . 1
F 01 05 10 15 20 25 30 35 38 .
* * * * * H 美自動翻訳システム * * * * *
B ** JAPANESE-ENGLISH AUTOMATIC TRANSLATION **
B 少女に彼は本をあげた.
B He gave a book to a girl.
B He gave a book to a girl.
B 彼はヨーロッパの人口が5000万を超えた年に誕生した。
B He is in Europe whose population exceeded 500 million in the year he was born.
B 彼はヨーロッパの人口が5000万を超えた年に誕生した。
B He is in Europe whose population exceeded 500 million in the year he was born.
B 彼はヨーロッパの人口が5000万を超えた年に誕生した。
B He is in Europe whose population exceeded 500 million in the year he was born.

F 01 . . 05 . . 10 . . 15 . . 20 . . 25 . . 30 . . 35 . . 38 |
ENTER >

Figure 2. A sample output of the Fujitsu's Japanese-to-English translator.

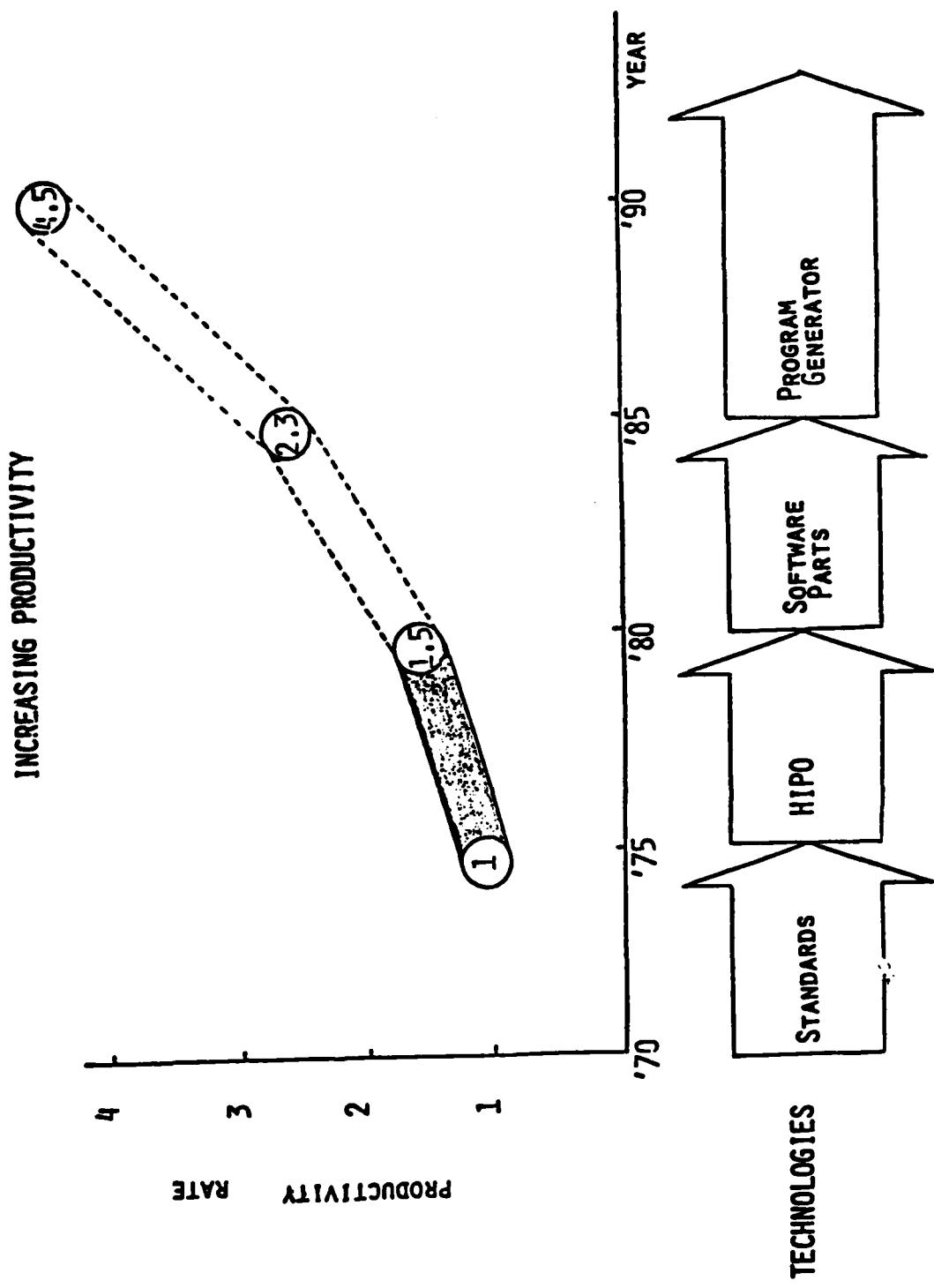


Figure 3. Hitachi SK's projection of software productivity

⑩ フチウ ソフテア ワークス
FUCHU SOFTWARE FACTORY

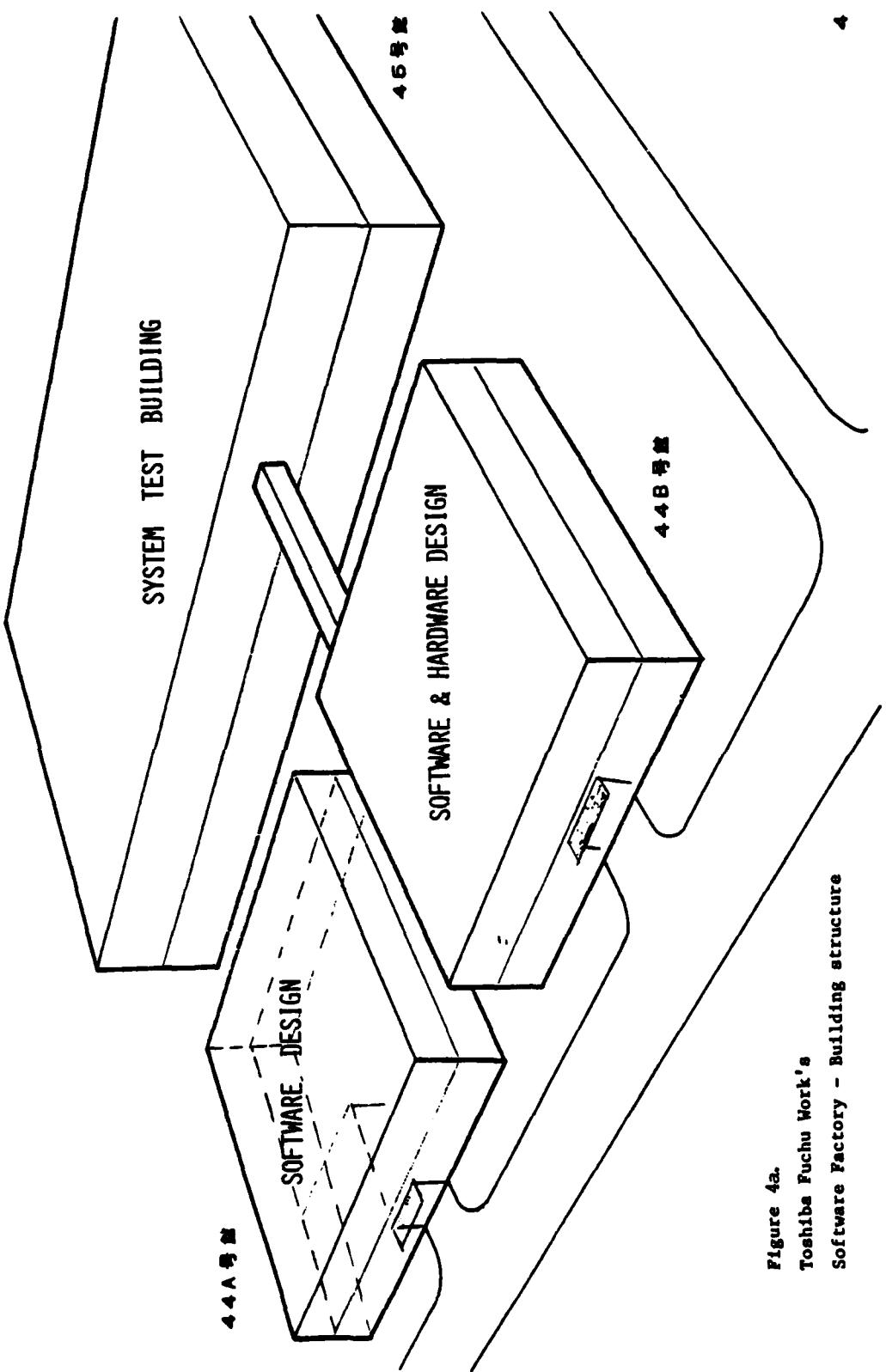


Figure 4a.
Toshiba Fuchu Work's
Software Factory - Building structure

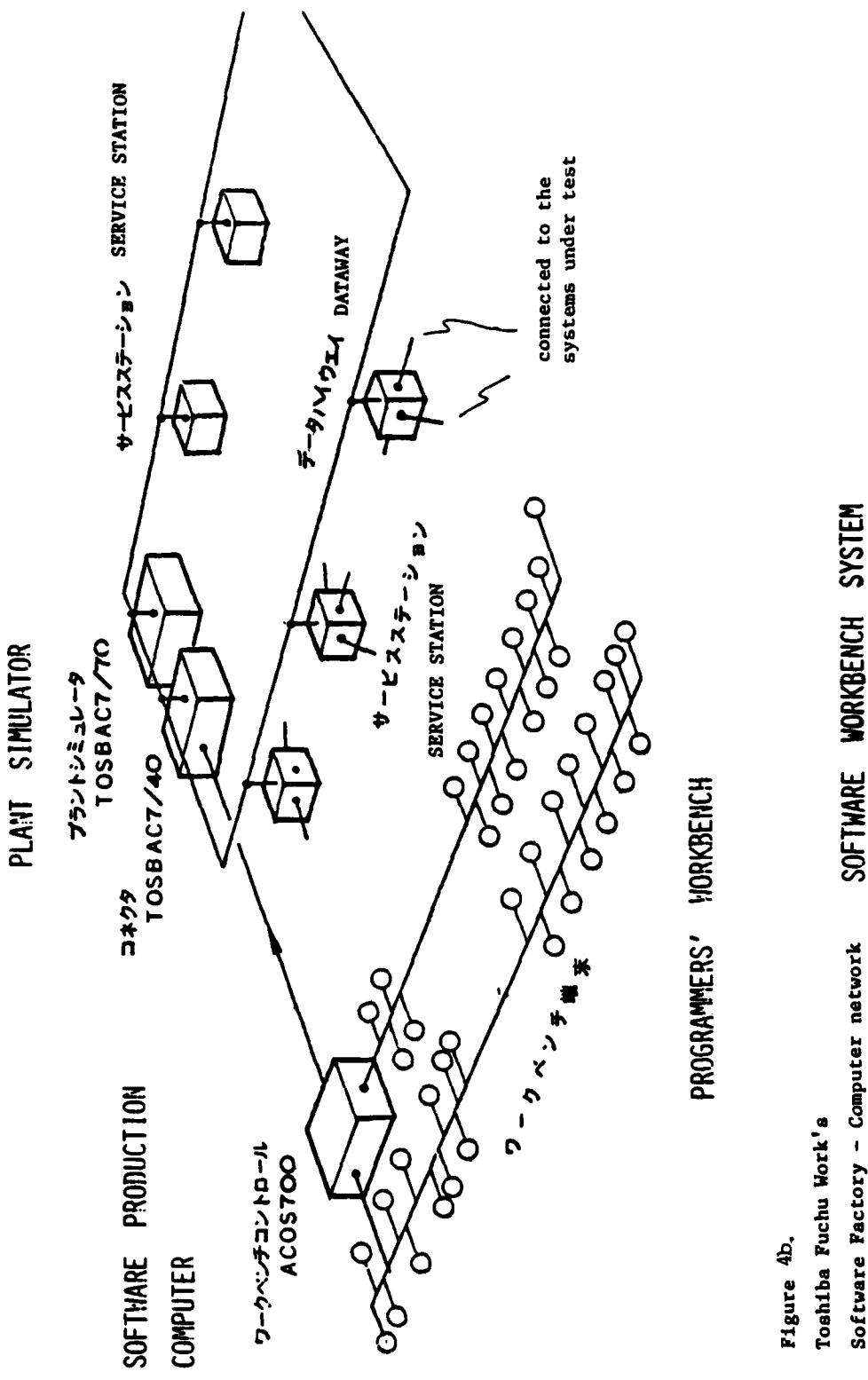


Figure 4b.
Toshiba Fuchu Work's
Software Factory - Computer network

SOFTWARE WORKBENCH SYSTEM

PRODUCTIVITY RISE IN FUCHU SOFTWARE-FACTORY

生産性

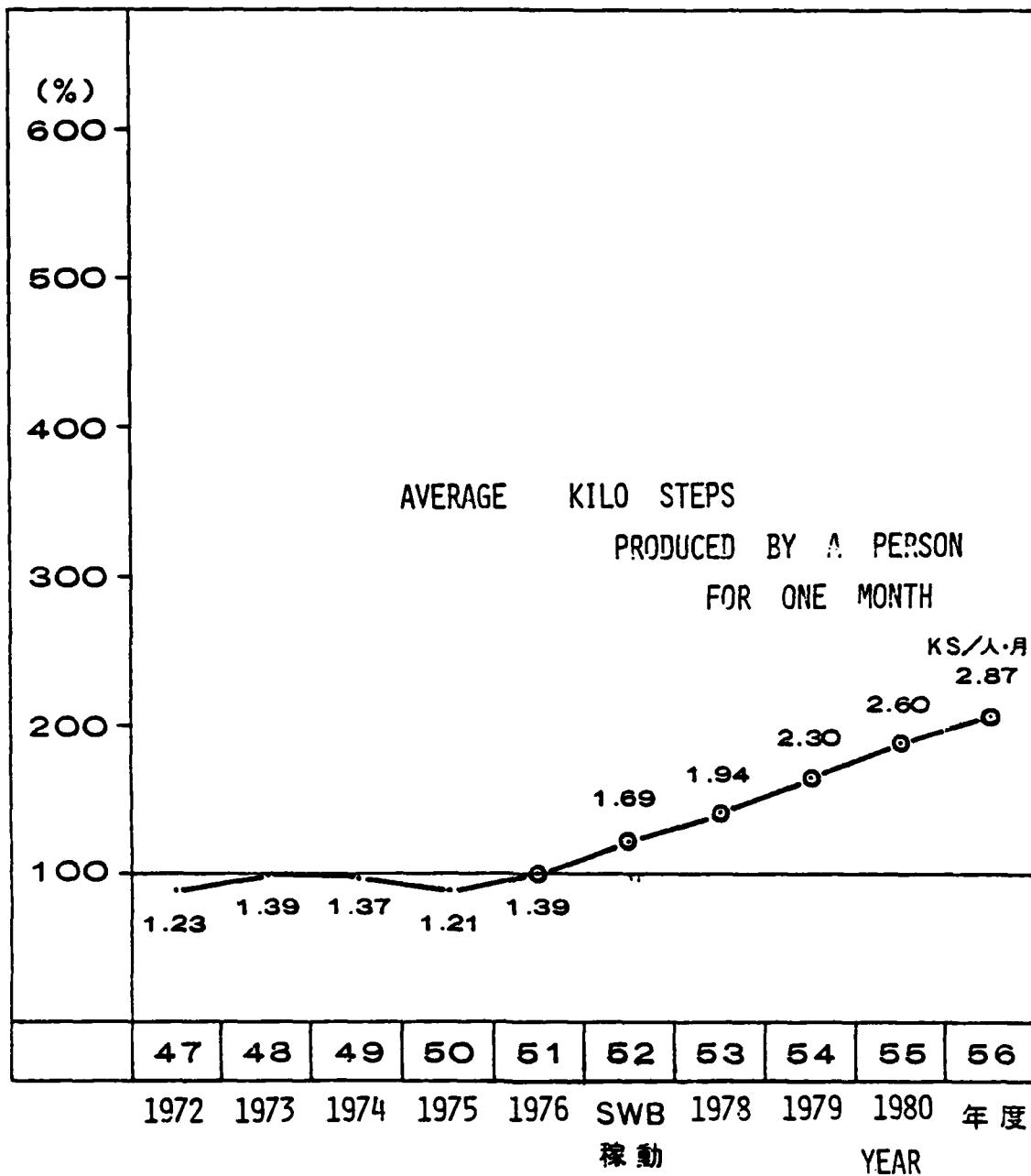


Figure 5. Toshiba Fuchu Work's Software Productivity

THIS YEAR 1977
SWB SYSTEM
STARTS

PHYSICS AT THE INDIAN INSTITUTE OF TECHNOLOGY DELHI

Leon H. Fisher

INTRODUCTION

A report covering electrical engineering at the Indian Institute of Technology Delhi (IIT Delhi), by N. M. Blachman appeared in this *Bulletin*, 5 (4), 10 (1980). The present report covers physics at IIT Delhi. For the convenience of the reader, a few general points made by Dr. Blachman are also made in this report.

After World War II, India established five small technical institutes designed to be of the very highest quality. These institutes were to provide centers of excellence for teaching and research in science, engineering, and technology and are known as the Indian Institutes of Technology. India is investing an enormous amount of educational resources in these institutes; other engineering educational institutions of comparable size receive one tenth to one twentieth as much support. It was hoped that these institutes would help India become a modern industrialized society, and would help develop products for the international market. However, some charges have been levelled against these elite institutions; for example, that many IIT graduates are not serving their country. Graduates easily find employment abroad, and many of those that do remain in India go into high management positions.

The names and dates of establishment of these institutes and the numbers of students, including graduate and undergraduate, are now given:

Indian Institute of Technology Bombay	1958	2400 students
Indian Institute of Technology Delhi	1961	2000 students
Indian Institute of Technology Kanpur	1960	2000 students
Indian Institute of Technology Kharagpur	1950	2700 students
Indian Institute of Technology Madras	1959	2400 students.

Each IIT (except IIT Kharagpur) was established with the support of a foreign country, and each of these four institutes maintains connections with the country which helped establish it. IIT Bombay was founded with the assistance of the U.S.S.R. (and UNESCO), IIT Delhi with the help of the U.K., IIT Kanpur with the help of the U.S., and IIT Madras with the help of West Germany. In some cases, the country associated with the founding of a particular institute still provides some support. Talks were initiated with Japan about helping establish an IIT, but nothing came of them.

The IITs are the responsibility of the Ministry of Education, Social Welfare, and Culture of the Government of India. This arrangement is in contrast to the situation for most universities in India where the responsibility is shared by the central government and the state government in which the institution is located. There is one central administrative body for all five IITs, the IIT Council, established by the Government of India. The Minister for Education, Social Welfare, and Culture of the Government of India is the chairman of the Council. Other IIT Council members include the five chairmen of the Boards of Governors of the five IITs (each IIT has its own administrative body, a Board of Governors, which is responsible for the administration of its own campus). The Board of Governors of each IIT consists of a chairman (selected by the Government of India), the Director of the Institute, six members appointed by the State Governments, four members appointed by the IIT Council, and two appointees from the Senate of the particular IIT concerned. The Senate of each IIT determines the academic policy of its own campus.

Of the forty to fifty thousand applicants applying for undergraduate admission each year to the IITs, only 1200 are accepted. With very few exceptions, admission to undergraduate programs in the IITs is based on an examination (conducted in English), the IIT Joint Entrance Examination (IITJEE). The IITJEE is also used as an admission examination for the undergraduate program of the Institute of Technology of Banaras Hindu University. The examination covers English, mathematics, physics, and chemistry. Students must be no older than 20 years and eight months old at the time of admission, except for scheduled castes and scheduled tribes in which case the upper age limit is relaxed up to five years. Indians living abroad on government service may have their children admitted directly by substituting other examinations for the IITJEE. A few foreign students sponsored by the Ministry of Education, Social Welfare, and Culture of the Government of India are admitted into undergraduate programs. Nine such students were admitted in 1979/80; they came from Iran, Iraq, Jordan, Malaysia, U.S.A., and Zambia. The students who are admitted to the IITs are among the best students in the country. However, not all of the best science and engineering students go to the IITs. Other institutions, such as the Indian Institute of Science, Bangalore, the Birla Institute of Technology and Science (especially in electronics), the University of Roorkee (especially in civil engineering) attract excellent science and engineering students. Some of the best instrumentalists are trained at the Madras Institute of Technology. Some excellent science and engineering students go abroad for their undergraduate education. By and large, the students who attend the IITs are middle class, the wealthier ones having other alternatives. IIT faculty members are generally considered to be among the best in the country.

IIT DELHI

IIT Delhi is located in New Delhi which has been the capital of India since 1912, first under British rule and then after independence. Delhi, a city with a history of more than three thousand years, and New Delhi (founded in 1912) are contiguous communities and together they constitute the third largest city in India. The population of Delhi at the last census (1971) was about 3.3 million (it is now over four million) and that of New Delhi was about 300,000.

IIT Delhi was formed from the College of Engineering and Technology, Delhi which at the time was affiliated with Delhi University. (In India, every institution of higher education, if it is itself not a university must be "affiliated" with a university. This means that the instruction, examinations, etc., are overseen by the university and the degrees are actually granted by the university. Some Indian universities fulfill only this function and have no students of their own. The University of London which was founded in 1836 as an examining body, and only became a teaching body in 1896 served as the model for Indian "affiliating universities.") In 1963, IIT Delhi was declared to be an "Institute of National Importance," and was given the status of a university with powers to determine its own academic policy and to award degrees. (In India, there are nine "institutes of national importance" and eleven institutions which are not universities which are given "the status of a university." Each ITT has "the status of a university.")

At the time of its establishment, the primary objectives of IIT Delhi were to:

- offer instruction in applied sciences and engineering at a level comparable to the very best in the world,
- to provide facilities for graduate work and research.

In 1970, three more objectives were added:

- to provide leadership in curricular planning, laboratory development, and examination systems,
- to undertake faculty development programs (faculty development means bringing faculty up to date, retraining them in newer fields, etc.) for its own staff and for the teaching staffs of other engineering colleges in India,
- to develop close collaboration with industry through exchange of personnel and undertaking projects for industry, and
- to develop strong collaboration with other academic and research institutions in the country.

IIT Delhi has a beautiful 320-acre campus. It is located in an historic area known as Hauz Khas. Students must live on campus, although a few exceptions are made for students in Ph.D. programs. Residential facilities on campus are also provided for the faculty. (Providing housing for university faculty is quite common in India, but poses a serious postretirement residence problem since the housing must be relinquished on retirement.)

Twenty percent of undergraduate admissions are reserved for special admissions: fifteen percent for candidates belonging to scheduled castes and five percent for those belonging to scheduled tribes. Admission standards are different for such candidates. Annual undergraduate student expenses including tuition, room and board amount to about 1700 rupees per annum (about \$170 U.S.). Twenty-five percent of the undergraduates are on scholarships based on both ability and need and these cover practically all expenses including room and board. Such scholarships are reserved for students whose families have annual incomes of less than 6000 rupees (about \$600 U.S.). The Institute provides scholarships for another ten percent of the undergraduate student body on the basis of need alone. Generous scholarships are also provided to graduate students.

As already mentioned, IIT Delhi was founded with the help of the U.K. IIT Delhi has a close association and academic and research collaboration with the following institutions in the U.K.: Imperial College of Science and Technology, the University of Manchester Institute of Science and Technology (an institution associated with the University of Manchester), the Universities of Birmingham, Loughborough, Leeds, and Southampton as well as with the Royal College of Surgeons. Although the Government of India provides the funds for operating IIT Delhi, the British Government pays for the cost of any equipment purchased in the U.K. and also pays for visiting professors and technical experts from the U.K. The stated purpose of this collaboration is to undertake joint research and development projects to serve the needs of Indian industries. A group in London known as the Imperial College Delhi Committee functions as consultants to the U.K. Government on the collaboration program. The Committee includes representatives of the Universities of Birmingham, Leeds, Loughborough, Manchester, and Southampton as well as of Imperial College.

In addition to its collaboration with U.K. institutions, IIT Delhi has recently established collaboration arrangements with the Swiss Federal Institute of Technology, Zurich, in biochemical engineering; with various French institutions such as the Institute of Research in Information and Automation (IRIA); the University of Paris, and the Centre National de la Recherche Scientifique (CNRS) in atmospheric science, biomechanics, solid

state physics, microelectronics, bioconversion and solar energy; the National Technical University, Trondheim, Norway in industrial tribology, machine dynamics and maintenance engineering; the Institute for Textile Technology, Reutlingen, Federal Republic of Germany and the University of New South Wales, Kensington, Australia in textile technology; the Institute of Meteorology and Hydrology, Sweden in water resources development; and with the Chalmers University of Technology, Gothenburg, Sweden, in electromagnetic transmission and radiation.

IIT Delhi has the following departments (number of faculty in each department is also given):

- Applied Mechanics (23)
- Chemical Engineering (21)
- Chemistry (24)
- Civil Engineering (29)
- Electrical Engineering (43)
- Humanities and Social Sciences (11)
- Mathematics (25)
- Mechanical Engineering (37)
- Physics (32)
- Textile Technology (18)

In addition, IIT Delhi has a number of centers of an interdisciplinary nature, with some of the personnel having academic rank. Many of these centers have instructional programs, mostly graduate, including the Ph.D. degree. These centers have academic associations with regular academic departments, but are administered separately. Their funds come from a separate budget. The names of the centers, along with a brief description of their activities and the number of personnel follow:

- Center for Applied Research in Electronics (12 plus 11 associated faculty)

This center was initiated in 1971 with financial assistance from the Ministry of Defense. The major activities consist of:

- Radar and sonar signal processing (recently an underwater electronics laboratory was set up)
- Microelectronics
- Microwaves and millimeter waves

- Center for Atmospheric Sciences (6)

This center was established in 1979 for applications of mathematics to biofluid dynamics and to meteorological fluid dynamics. As already mentioned, scientific collaboration programs exist with French universities (under the Indo-French Scientific Exchange Program) as well as with universities in the U.K. Scientists at the center include mathematicians, meteorologists, physiologists, engineers, and hydrologists.

- Biochemical Engineering Research Center (8)

The major efforts of this center relate to bioconversion of waste cellulose materials into energy, chemicals, and microbial protein. The center's objectives also include development of village level technology for utilization

of agricultural residues for biogas and other chemical products. The center has facilities for conducting pilot plant experimental runs on fermentation processes.

- Center for Biomedical Engineering (II)

This center is jointly operated with the All-India Institute of Medical Sciences, Delhi, and there is a common faculty. Facilities for experimental research are located at both institutions. Work is being carried out in the fields of biomedical engineering, data processing, biological experimentation, and instrument development.

- Center of Energy Studies (35 plus 70 associated faculty)

This center was established in 1975, and now has a special grant from the Ministry of Education, Social Welfare, and Culture. The research and development activities of the center extend over all of the science and engineering departments of the Institute. The fields of activities are:

- Electrical energy systems: analysis, stability, optimization and control
- Liquefied fuels and chemical feedstocks from low grade coals
- Utilization of unconventional synthetic fuels
- Solar energy utilization: solar thermal applications, photovoltaic conversion, selective coatings
- Laser induced fission
- MHD (magnetohydrodynamic) power generation

- Industrial Tribology, Machine Dynamics and Maintenance Engineering Center (14 plus 11 associated Faculty)

This center was set up with the collaboration of Norway to undertake industry-oriented research and development work in the fields of friction, wear, lubrication, prevention of wasteful practices, wear analysis, energy conservation, maintenance, condition and machine health monitoring, design audit, failure mechanics, signature analysis, vibration and noise in machines, fault diagnosis, and reliability.

- Center for Materials Science and Technology (10 plus 10 associated faculty)

There are three principal areas of activity. They (and their subdivisions) are:

• Solid State Electronic Materials

Amorphous and photoconductive semiconductor materials
Crystal growth and characterization
Electrographic materials
Epitaxial growth and characterization of piezoelectronic insulator materials

• Polymer Science and Materials

Synthesis of elastomers, high temperature polymers and biomaterials
Polymer blends and composites

**Structure-property relationship in polymers
Engineering plastics
Polymerization kinetics and reaction design**

• Building Materials

**Fiber-reinforced concrete
Special concrete for ocean environment
Thermal conductivity of concrete
Long-term behavior of concrete in structures
Acceptance testing of concrete, bricks, and other building materials**

- Center for Rural Development and Appropriate Technology (2 plus 20 associated faculty)

The center was opened in 1979 to initiate and coordinate research for the benefit of rural communities and to transfer such technology to villages. The center is working in three major fields:

• Software Activities

**Development of techniques for carrying out socio-economic surveys and developing rapport with rural areas
Identification of problems connected with the development of the rural sector and its social and economic implications**

• Planning

The center has developed micro- and macro-level planning procedures in eight villages in Haryana which have been adopted by IIT Delhi. Projects include:

**Rural health care delivery systems
Providing clean drinking water
Development of efficient implements**

• Appropriate Technology

**Development of suitable water lifting mechanisms
Development of nonconventional energy sources
Development of equipment for processing various food items
Development of equipment to be used by handicapped people so that they can work
Development of suitable units for recycling rural sector waste
Suitable economic approaches for improving agricultural output of unused land**

- Center for Systems and Management Studies (3 plus 22 associated facility)

This center was opened in 1975. The areas of research being undertaken by the center are:

- Transportation**
- Water resources**

- Resources engineering
- Urban buildings systems
- Management of human resources
- Energy systems
- Health care systems (in collaboration with Center for Biomedical Engineering)
- Organization development
- Corporate planning

- Computer Center (22, this includes 14 system operators and programmers)

The center now has an ICL 2690 system which was obtained under the Indo-U.K. Collaboration Program.

- Instrument Design Development Center (17, including six Ph.D.s)

The center consists of:

- Electrical and electronic design section
- Industrial design and product architecture
- Mechanical design and prototype development workshop
- Optical design and production laboratory

The center is involved in research and development activities in measurement in collaboration with various organizations in the country. The center also designs and develops instruments and laboratory equipment for the various institute departments.

Five year undergraduate programs are offered in:

- Chemical Engineering
- Civil Engineering
- Electrical Engineering
- Mechanical Engineering
- Textile Technology
- Chemistry
- Physics

The first five programs each admit about 45 students per year and lead to the degree of Bachelor of Technology (B. Tech.) and the last two each admit about 20 students per year and lead to the M.S. degree. Both the B.Tech and the M.S. are considered to be undergraduate degrees. IIT Delhi also offers a M.Sc. and a M. Tech. degree which are graduate degrees and which must be distinguished from the M.S. degree. Two year graduate programs leading to the degree of Master of Technology (M.Tech.) are offered in many subjects by most of the departments and centers indicated above. In addition, there is a two year diploma program for students sponsored by the Defense Ministry on Naval Construction. This program is run with the collaboration of the Indian Navy and is only open to sponsored officer-trainees of the Indian Navy.

Two year graduate programs leading to the M.Sc. degree are offered in chemistry, physics, and mathematics. Post-M.Sc. diploma programs and Ph.D. degrees are also offered, as well as a degree identified as a D.I.I.T., the nature of which I have not been able to determine.

There are 1150 undergraduate students, the rest are studying for graduate degrees. At present, about 80 Ph.D. degrees are awarded each year. About two hundred Ph.D. degrees have been granted by the Institute. There are about 30 foreign students.

A number of engineering schools in India send their faculty to IIT Delhi to pursue graduate work for the M.Tech., M.Sc., or Ph.D. degree under a program known as the Quality Improvement Program of the Government of India. During 1979-80 four such faculty received M. Tech. and six received Ph.D. degrees. During the same academic year the Institute admitted three faculty from various engineering colleges in the country for the M. Tech. program and 17 others for Ph.D. programs.

THE PHYSICS DEPARTMENT

The department is very active in research and is especially proud of the fact that four of its faculty members have been awarded the prestigious Shanti Swarup Bhatnagar Prize for science and technology; having four recipients of this award in one department is very rare. Research activities in the physics department include interaction of electromagnetic fields with plasmas and semiconductors, lattice dynamics, optical waveguides and retinal receptors, solid state physics, solid state electronics, crystal growth and dislocations, applied optics (including holography, speckles and optical data processing), quantum and statistical optics, laser Raman, photon correlation and modulation spectroscopy, thin films including electret physics, Mössbauer spectrometry, optical and electrical properties of organic and inorganic semiconductors, high temperature properties of materials, magnetohydrodynamics, solar energy, electron microscopy and amorphous materials and ferroelectrics. There is very little nuclear physics going on, although some hadron nuclear interactions have been studied with nuclear emulsion detectors exposed to 200 GeV/c and 400 GeV/c proton beams at the Fermi Laboratory. Some emulsion plates are exposed at the Bhabha Atomic Research Center at Trombay (near Bombay), and the tracks are analyzed by IIT Delhi physicists.

In addition to the research programs being carried on in the physics department, the department is actively associated with the Centers for Materials Science and Technology, Energy Studies, Biochemical Engineering Research, and Biomedical Engineering.

There are forty students in the physics M.Tech. program, twenty graduating each year. These forty students are equally divided between the applied optics and the solid state options. In addition, at the present time five students per year are being admitted to the opto-electronics and optical communication option for the M.Tech. which is jointly administered by the departments of electrical engineering and physics (as previously mentioned). The M. Tech. degree in opto-electronics and optical communications is usually a terminal degree and is oriented toward applications. It prepares a student for employment in industry, especially the optical industry, and the national laboratories. The number of students in this joint program will eventually be doubled.

The physics department has recently started a two year M. Sc. program. Students with a B. Sc. degree from any university are admitted to this program after passing a qualifying test conducted by the department. There are less than twenty students admitted each year to this program. The M. Sc. program in physics is a broadly based one but is rather applied in nature. By the end of the program the students have had specialized courses in applied optics, solid state physics, plasma physics, etc.

To be admitted to the Ph.D. program in physics, one must either have an M.S. or M.Sc. in physics or a B. Tech. in engineering; candidates with ordinary bachelor degrees in

science or engineering are not accepted. Sometimes students with the M. Tech. degree in opto-electronics and optical communications join the Ph.D. program in physics, but this is unusual. A student takes four years, on the average, to obtain a Ph.D. degree in physics.

The chairmanship of the physics department rotates every three years, and the administrative duties in the IIT Delhi physics department are shared by the entire faculty. The teaching load in the physics department is six or seven hours a week, but is five hours a week for the chairman indicating that the chairman is not expected to spend all his time on administration.

At the present time, B. B. Tripathi, a theoretical physicist, is the head of the department. He is interested in electron phonon interactions, lattice dynamics, pseudopotentials and phase transition problems. He spent three months in 1976 with Walter Harrison at Stanford University. He was a student of B. Dayal, a theoretical physicist, and A. R. Verma, spectroscopist and crystallographer, when Verma was on the faculty and head of the physics department at Banaras Hindu University from 1959-1965. (As mentioned in the preceding issue of this *Bulletin*, Verma is now Director of the National Physical Laboratory, New Delhi, although a search is now going on for a successor as Verma has reached retirement age.)

A list of the physics faculty indicate, that at present, of the 32 physics faculty members which are listed, approximately one third of these hold Ph.D. degrees from the U.S.A. and Great Britain.

A few of the physics department's activities are now discussed.

Lattice Dynamics

A group of workers associated with B. B. Tripathi is studying the lattice dynamics of metals, semiconductors, and mixed crystals. The research falls mainly into two parts:

. Elastic force model approach

In the elastic force model approach, the thermal properties of metals have been investigated including the central forces, both type of the angular forces, viz., de Launey and Clark, Gazis and Wallis and the volume forces. It has been shown that in the case of b.c.c., f.c.c. and h.c.p. metals, the two angular forces are equivalent. An inference has been drawn that de Launey type angular forces are also rotationally invariant.

. Pseudopotential approach

In the pseudopotential approach, the model potential of Harrison has been optimized to study the lattice dynamical properties, elastic properties, magnetic and thermodynamic properties, electronic band structure, superconducting properties and the electrical properties of liquid metals. For diamond type lattices, a model potential has been proposed which takes into account the physics of the problem in a simple parametric way. The same model potential has been used to obtain properties of semiconductors with good success. For noble and transition metals, a local model potential has been investigated for explaining various solid state properties. The phonon anomalies in the transition metals phonon spectra have been successfully explained by means of a model potential and the consideration of effective

mass in the free-electron approximation. The modified rigid ion-model has been successfully applied to the study of the elastic properties and the phonon dispersion curves of mixed crystals. The lattice dynamics of alkali halides in the rock salt structure has been studied using the quantum mechanical overlap potential due to Harrison.

Plasma Physics

Plasma physics has been pursued at IIT Delhi since 1964. At present, about thirty scientists led by M. S. Sodha and D. P. Tewari are involved in plasma physics and they constitute one of the largest groups working in plasma physics in India. Sodha is the most senior professor in the department and is now working in solar energy, plasma physics, and self-focusing effects in lasers. He had an ONR program from 1968 to 1973 with John Satkowski, Director of the Power Program of ONR. Most of the work in plasma physics at IIT Delhi has been supported by the Institute itself and by the Department of Science and Technology (of India) and the Indian National Science Academy. Substantial funding has also been received from NSF, ONR, and NOAA. Over the years about forty-five Ph.D. degrees have been awarded in plasma physics. The effort is being pursued both in the Physics Department and in the Center of Energy Studies. As already mentioned, the Center of Energy Studies has two plasma related projects, laser fusion and magnetohydrodynamic power generation. IIT Delhi has recently recognized the importance of plasma physics by creating a "Cell for Science and Technology of Plasmas" within the physics department.

The group's activities are in the following areas:

- Interaction of electromagnetic waves with gaseous plasma

The work in this area up to now has primarily been theoretical. However, in early 1980 experimental facilities to study electrostatic wave propagation and high power microwave interaction with bounded plasma columns began to be installed. A modest plasma laboratory is now in operation. The problems being investigated are:

- . Linear electromagnetic wave interaction with plasmas
- . Interaction of high power electromagnetic waves (lasers, microwaves, radio waves) with plasmas
- . Self-focusing of laser beams and its influence on other nonlinear phenomena in plasmas

- Solid state plasmas

Work in this area is theoretical and involves elemental and compound semiconductors and semimetals with degenerate and nondegenerate carriers, parabolic and nonparabolic energy bands, simple model or many valley band structures. Nonlinear phenomena such as harmonic and combination frequency generation and the self-focusing of electromagnetic waves have been investigated in semiconductor plasmas.

- Magnetohydrodynamic (MHD) power generation

Theoretical studies in 1965 on the physics of colloidal plasmas and its application to MHD power generation marked the beginning of MHD activity

at IIT Delhi. Experimental facilities have been set up for the investigation of transport properties of seeded combustion plasmas and electrode phenomena. Studies on the optimum seeding of helium plasmas with cesium for obtaining maximum effective conductivity have been carried out both for the equilibrium as well as the nonequilibrium cases. The effective conductivity in seeded gases with magnetically induced ionization has also been studied. The electrical conductivity of dust laden gases has been shown to be enhanced by thermionic emission from the dust particles and also by photoemission if the gas is irradiated with ultraviolet light. The reduction in electron density of a plasma by the attachment of electrons to water droplets sprayed from outside has been studied. Experimental investigations have been carried out on the electrical conductivity of seeded oxy-acetylene and seeded air-acetylene products. Both systems were found to have high electrical conductivity. Further investigations are being undertaken to evaluate the suitability of hydrogen, coal, and biogas as fuels in MHD generators. Experimental and theoretical studies have been carried out of the cathode sheaths developed over cooled copper electrodes in seeded (K_2CO_3) products of combustion of LPG and oxygen. A theoretical model has been developed for the total potential drop between electrodes taking into account the effect of ambipolar diffusion. Current between electrodes is found to increase due to thermionic emission of electrons from the cathode surface because of the lowering of work function due to seed deposition on the cathode surface. A project entitled, "Investigations on colloidal plasmas and its application to MHD power generation," was supported by ONR from 1972 to 1977. A research project, "Studies in MHD power generation," is at present being supported by the NSF.

The titles of some of the papers published by the group in 1981 follow:

- "Ionization instability in nonequilibrium MHD generators; effect of diffusion"
- "Electrical conductivity of seeded combustion products water gas-air system"
- "Potential drops inside MHD generators"
- "Excitation of an ion-acoustic wave by two whistlers in a collisionless magnetoplasma"
- "Generation of an electrostatic pulse and second harmonic EM pulse in a magnetoplasma"
- "Nonlinear interaction of a Gaussian EM beam with an electrostatic lower hybrid wave Brillouin scattering"
- "Growth of laser ripple in a plasma and its effect on plasma wave excitation"
- "Change in electron mass and collision frequency due to acoustic wave propagation in semiconductors"
- "Decay instability of a Whistler in a plasma"
- "Temporal growth rate of filamentation instability in a strongly ionized magnetoplasma"

Thin Film Laboratory

K. L. Chopra organized the Thin Film Laboratory in 1970 and still leads the group. He is writing a book on "Applications of Thin Films to Solar Cells." Forty people are now involved in the laboratory; thirty of them are scientists and of these eight are faculty members. It is the largest activity in the physics department both in number of people and amount of money involved. Ninety percent of the work is experimental. The stated aim of the group is to develop devices through fundamental studies in solid state physics, but the emphasis is on basic research. In addition, the laboratory does consulting work for industry and is involved in technology transfer in electronics, optics, vacuum technology, and surface analysis. The laboratory receives research grants from various government agencies. The laboratory has facilities for depositing films of metals, insulators, semiconductors, and alloys in amorphous as well as polycrystalline and single crystal form by thermal evaporation, sputtering, ion plating, electrolysis, solution growth, chemical vapor deposition, splat quenching, and melt spinning techniques. The facilities allow the study of the structural, thermal, electrical, magnetic, and optical properties of the films. The laboratory is unique in India in that it has deposition, analytical, measurement, device fabrication, and evaluation facilities in one location. The laboratory has facilities such as an electron microscope, a scanning Auger microprobe (SAM)(the only one in northern India), electron spectroscopy for chemical analysis (ESCA), ultraviolet, visible and infrared double beam spectrophotometers, and a differential thermal analyzer.

Some of the activities of the group are now described.

. Amorphous Materials

Work has been carried out on amorphous films of Ge based alloy/compound semiconductors. The presence of adatom mobility during the formation of amorphous materials has been demonstrated and the microstructural defects such as voids and electronic defects such as dangling bonds on the electrical and optical properties of adsorbed Ge has been established. The introduction of impurities (up to 40 weight percent) drastically modifies the electron transport and optical processes. Anomalously large photo-induced contraction, chemical etching, and electrochemical doping effects have been discovered in obliquely deposited amorphous Se-Ge films. The large photostructural changes are being used for submicron photolithography and high resolution reprography and image storage.

. Gradient Index Optical Coatings

Inhomogeneously mixed and multilayer optical coatings of ZnS and MgF₂ have been developed to obtain materials with variable and spatially varying optical constants for applications in integrated optics.

. Polymer and Metallocopolymer Films

A solution growth technique has been developed to prepare pure and doped polymer films with such materials as Cu, Ni, Cd, and Co which change the conductivity of the polymer films by six to eight orders of magnitude.

. Conduction Processes in Metal Films

Studies of the size effects and transport properties of structurally and

electronically (impurity) disordered metallic systems have helped separate the contributions of the structural, electronic, spatial, and spin disorder effects on the electronic properties of Cu-based alloy films.

. Solution Grown Variable Gap Semiconductor Films

A chemical deposition technique has been developed to prepare binary, ternary, and quaternary alloy semiconductors of variable composition with desired electrical, optical, and opto-electronic properties. Lead mercury films of optical bandgap ranging from 0.2 to 1.2 eV have been prepared and used for IR detection in the three to eight micron region with high sensitivity. Chemically deposited CdSe films have been utilized to fabricate photoelectrochemical cells for solar energy conversion. Efficiencies of three percent have been achieved on areas of several square centimeters.

. Thin Film Solar Cells

Large area thin film Cu₂S/CdS solar cells are being developed. Efficiencies of eight to 10 percent have been achieved on small area cells prepared by both vacuum evaporation and spray pyrolysis. Present interests are focused on reproducing this performance on large area (50 cm²) devices and stabilizing the cells against degradation (primarily by doping of Cu₂S and by encapsulation).

. Selective Solar Coatings for Photothermal Conversion

. Transparent Conducting Oxide Semiconductors

. Rapidly Quenched Materials

Metallic and nonmetallic alloys exhibiting unusual metastable structures have been prepared by splat quenching and melt spinning under vacuum. The melt spinning technique has been used to form ribbons of metallic glasses.

. Tribological Coatings

An rf and dc magnetron sputtering facility has been established to prepare alloys of high temperature refractory metals such as Mo, W, and Ta and insulators such as oxides and carbides for tribological applications and corrosion resistance.

The titles of some recent papers published by the laboratory are:

- "Formation of metastable solid solutions in the Pb-Ge system"
- "Annealing characteristics of tin oxide films prepared by spray pyrolysis"
- "Photothermal performance of selective black nickel coatings"
- "Giant photocontraction effect in amorphous chalcogenide thin films"
- "Photo-induced chemical changes in obliquely deposited amorphous Se-Ge films"

- "Solution growth of CdSe and PbSe films"
- "Growth kinetics and polymorphism of chemically deposited CdS thin films"

Theoretical Work in Fiber Optics

Research on theoretical aspects of light propagation through homogeneous and inhomogeneous core optical fibers and integrated optical waveguides was started at IIT Delhi as early as 1971 by a group working on optical waveguides. This group has developed approximate techniques such as perturbation calculations, WKB, and variational methods to study the transmission characteristics of graded-index waveguides for which no exact solutions exist. The applicability of these approximate techniques have been tested, wherever possible, with solutions obtained using numerical techniques. Existence of exact solutions to specific refractive index distributions have also been demonstrated and these exact solutions have been used to check the accuracy of the approximate approaches. For example, the effect of a cladding on the modes of a parabolic index core fiber has been treated using a perturbation method and the results compared with those of other authors. The same perturbation method has also been used to predict the cutoff behavior of some of the lower order modes in general graded-core fibers. The effect of an axial dip in the refractive index profile (which invariably occurs in state of the art optical fibers) on the pulse dispersion and the zero-dispersion wavelength have also been investigated. A variational method has recently been used for determination of the modal field of a single mode graded-core fiber. The approach has been shown to yield highly accurate results. These modal fields have been used for studying splice loss between two single mode fibers.

Exact solutions of the scalar wave equation have been obtained for specific refractive index variations which are obtained during the experimental fabrication of integrated optical wave guides. These solutions are useful for analyzing these waveguides for their application in various integrated optical structures. Since single mode fiber directional couplers are also finding application in various devices used in optical communication and fiber optics sensors, an exact solution to such a problem has been obtained and the results compared with more cumbersome numerical calculations of other authors. Theoretical analyses of strip optical waveguides and directional couplers used in integrated optics have also been made. Studies on mode coupling among various modes due to imperfections in the fiber have also been made. Several studies on pulse dispersion of optical fibers have been made.

I spent some time with A. K. Ghatak, a theoretical physicist, not only at IIT Delhi, but also subsequently in Tokyo. He is one of the active faculty members in fiber optics research. He used to work in nonlinear optics including propagation in nonlinear media. However, he left nonlinear optics about two years ago and now works exclusively on optical fibers. He has close connections with Professor Y. Suematsu of the Tokyo Institute of Technology and spent six weeks in Japan with Suematsu in the spring of 1981. Among other faculty members working on optical fibers are I. C. Goyal, M. S. Sodha, and K. Thyagarajan. Ghatak and Thyagarajan are coauthors of two books, *Contemporary Optics* (1978) and *Lasers Theory and Applications* (1981), both issued by Plenum. Ghatak and Sodha are coauthors of *Inhomogeneous Optical Wave Guides* (1977), also issued by Plenum. This book has just now been translated into Russian and Chinese. Ghatak and L. S. Kothari (Department of Physics, University of Delhi) are coauthors of *An Introduction to Lattice Dynamics* (1972), issued by Addison Wesley. Some recent publications by Ghatak and his colleagues are:

"A new method for tracing rays through graded index media"

This paper describes a rapid ray tracing method for graded index media which requires much less computational effort for a given accuracy than do existing methods.

"Variational analysis of directional couplers with graded index profile"

A variational analysis of graded optical directional couplers was developed which gives better results, with much less algebraic and numerical work, than the WKB method which has been previously used.

"Coupling of two parallel multimode parabolic index waveguides: an exact analysis in the weakly guiding approximation"

A modal analysis was carried out and was used to study the power exchange between two waveguides and a simple analytical expression was obtained for the coupling length in a case of practical importance.

"A variational analysis of single mode graded-index fibers"

A variational method was used to obtain the transverse electric field and the propagation constant of the fundamental mode of weakly guiding graded-index fibers. The method gives extremely accurate results in comparison to other methods in the practical region of single mode operation and does not involve much computational effort.

"Fundamental mode of graded-index fibers: simple and accurate variational methods"

Two approximations are presented for the fundamental mode of graded index fibers. The first is a one parameter analysis which involves computational effort comparable to that involved in the Gaussian approximation and yet gives much better results. The second is a two parameter analysis which gives much better results for all values of the dimensionless frequency V for most graded-index fibers than other approximations.

Ghatak and Thyagarajan also published a long chapter, "Graded Index Optical Waveguides: A Review," in *Progress in Optics* in 1980.

Optical Fiber Communication and Integrated Optics Laboratory

This laboratory for teaching and research and development was set up about two years ago. The laboratory was set up primarily to characterize optical fibers in terms of their transmission characteristics and to correlate these measurements with theoretical prediction. Such measurements include refractive index profile measurements of multimode fibers using the near field scanning technique, attenuation spectrum measurement using the cut back method, scattering loss measurement using an integrating sphere, single mode fiber characterization using the far field method, splice loss measurements between multimode as well as single mode fibers, electrical and optical characteristics of LEDs so as to determine their suitability as sources for optical communication. Efforts are also underway in the laboratory to develop an optical fiber communication system. An analogue system for voice transmission through optical fibers using an LED has been set up. A two-channel digital multiplex voice transmission using

multimode fibers is being set up. Basic pulse dispersion measurement experimental facilities are being developed.

In the area of integrated optics, fabrication of passive planar homogeneous and graded-index waveguides have been developed. The graded-index waveguides are being fabricated by means of Ag-Na ion exchange. Tapered waveguides have also been fabricated. The laboratory has setups for measuring the number of guided modes and the propagation constants of these modes. These experimental studies are being undertaken in order to fabricate, in the long term, low loss silica fibers and active integrated optical waveguides and devices based on lithium niobate technology.

Laser Spectroscopy Laboratory

This laboratory was recently established with the help of the Indo-French collaboration.

Photovoltaic Laboratory

This work is being led by S. C. Mathur. Attempts are being made to measure the Hall effect in low mobility, high resistivity materials. There is interest in ferroelectric materials which show pyroelectric effects so that these materials can be used as IR detectors. It is hoped that flat responses will be obtained over a wide range. Most semiconductor materials are limited in range. Ferroelectric hysteresis studies are being carried out in which polarization is measured as a function of electric field. Pyroelectric coefficients are being measured and thermally stimulated discharge currents are being measured in polymers. Xerographic work is also being pursued. DC corona produced by voltages between 15 and 18 kV is being used to charge a sample surface and decay is being measured for applications to photothermography. Work is also going on on a pyroelectric ferroelectric generator for transforming heat to electricity. This activity has about ten graduate students, four on ferroelectrics, five on organic photovoltaic systems, and one theorist.

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INTRODUCTION

This report covers the activities of the university Department of Physics and Astrophysics at the University of Delhi. For brevity it will be referred to as the Department of Physics and Astrophysics of the University of Delhi. What is meant by a university department will be made clear in the next paragraph.

The University of Delhi is a coeducational institution which was founded in 1922. It is one of the few universities administered by the central government. It obtains its funds directly from the University Grants Commission, an agency of the Indian Central Government. The University of Delhi is legally classified as a "teaching and affiliating institution." When universities were first set up in India, they did no teaching and were known as affiliating universities. They were established to serve as examining bodies and to recognize colleges which would then be affiliated with the university. For sixty years after the first universities were established in India, universities did no teaching. Gradually after World War I, they began to set up graduate departments and university colleges in which instruction was carried out. Such institutions which provide instruction and act as affiliating agencies with other institutions are now known as teaching and affiliating universities, the University of Delhi being an example. Some universities in India still only serve as administrative centers and granters of degrees for colleges affiliated with them and offer no instruction of any kind. Colleges which are affiliated with universities are private institutions.

The department which is described in the present report is what is known as a university department. In addition to the university departments of the University of Delhi, there are fifty seven colleges associated with the University of Delhi. Sixteen of them are known as Delhi University Colleges and are constituent colleges of the University; they are not affiliated colleges. The remaining forty one are affiliated colleges and the University of Delhi (in addition to providing instruction within its university departments and administering the Delhi University Colleges) acts as an administrative center for these affiliated colleges and as an agency to grant degrees to students in these colleges. All fifty seven of the colleges associated with the University of Delhi are in Delhi. (There are altogether 100 colleges in Delhi.) The Delhi University Colleges and the university departments of the University of Delhi have a combined enrollment of about 21,000; the colleges affiliated with the University of Delhi have a combined enrollment of over 57,000.

Delhi University Colleges only have lecturers, the lowest rung on the academic ladder (readers and professors are the two higher academic ranks) and offer undergraduate teaching only. However, affiliated colleges do offer graduate work.

THE DEPARTMENT OF PHYSICS AND ASTROPHYSICS

The department of physics and astrophysics of the University of Delhi used to provide instruction at both the undergraduate and graduate level, but around 1971 the growth of its graduate program caused the undergraduate instruction to be transferred to some selected Delhi University Colleges; at present, the department provides training only at the graduate level.

The department offers M.Sc., M.Phil., M.Tech. (Microwave) and Ph.D. degrees. [The M.Phil. and M.Tech. (Microwave) programs are of recent origin]. There are two streams, experimental and theoretical, in both the M.Sc. and M.Phil. programs. About 180, 55, and 10 students are admitted annually for the M.Sc., M.Phil. and M.Tech. (Microwave) degrees, respectively. The M.Sc. program lasts two years and there are about 300 in the program at any one time. The M.Phil. was introduced in 1977, and is a degree intermediate in level between the M.Sc. and Ph.D. and a dissertation is required. The M.Tech. (Microwave) program is small and is being financed for a five year period by the Electronics Commission. Over a hundred students are enrolled in the Ph.D. program. About fifteen Ph.D. degrees are awarded each year. About 75 percent of the Ph.D. students are experimentalists. During the last ten years, about 150 Ph.D. degrees have been awarded. Plans are under way to establish a regular postdoctoral program so that research activities initiated at the Ph.D. level by a student can be continued for five years (in exceptional cases, six or seven years) beyond the Ph.D. degree without interruption. It is felt that such a program is necessary for the best students in order to compete with world standards. The above activities are carried out with an average teaching load of 15 hours/week. (This is twice the teaching load that obtains in the physics department of IIT Delhi.)

University physics faculties in India are saturated (as they are in most countries). Many who received their Ph.D. degrees from the department teach in colleges. Some find employment in banks where they may become bank officers at relatively lucrative salaries. A small number are able to obtain employment at the Bhabha Atomic Research Center (BARC). Master of Science (M.Sc.) graduates often enter the civil service. Industry does not use physicists to any degree.

The department has been one of the major schools in India in theoretical physics for the last thirty years (particle physics, neutron physics, statistical physics, plasma physics, astrophysics, and atomic and molecular physics). In 1962, the Department was designated as a Center for Advanced Study in Physics and Astrophysics. (In 1964, the University Grants Commission began to foster professional excellence in universities through a major development program in support of "Centers for Advanced Study." The intention was to help establish activities comparable to the best in the world.) During the last fifteen years, experimental work has been initiated in low temperature physics, solid state physics, microwaves, x-ray crystallography, ionospheric physics, nuclear physics, high energy physics, high pressure physics and spectroscopy. At the present time, the faculty is about evenly split between theoreticians and experimentalists.

There are fifty faculty members of whom ten are professors, thirty are readers, and the rest lecturers. The department is carrying out work in the following fields:

THEORETICAL PHYSICS

- Quantum Theory of Fields
 - . Nuclear reactions
 - . Quark models
 - . Nuclear few body scattering
 - . Glauber scattering theory
 - . Strong and weak interactions including nonperturbative methods in quantum field theory
- Theoretical Particle and High Energy Physics

- Dynamical quark model and its application to particle spectroscopy
- Application of statistical mechanics to strong interaction dynamics
- Nonperturbative approach to confined and anharmonic systems

- Condensed Matter Physics:

• Neutron transport theory

A number of papers on neutron diffusion in water by L. S. Kothari and S. P. Tewari (and R. M. Bansal) have appeared. A relatively recent one was entitled "Neutron Diffusion in Water Containing $1/v$ and non $1/v$ Absorbers." In this paper, the Boltzmann equation was solved in the diffusion approximation using a neutron scattering kernel proposed by the authors.

• Ionized beam interaction with solids

• Pseudo equilibrium of neutron fields in crystalline moderators

• Lattice dynamics

Lattice anharmonicity has been studied theoretically in alkali metals and in diamond-structured crystals. Cubic and quartic contributions to the specific heat were obtained. This work was supported by the U.S. NSF.

• Calculation of electron correlations in condensed systems such as metals

This group has obtained wave-vector and frequency dependent dielectric functions of a low density one component plasma.

• Nonlinear static structure of electrons around a heavy positive impurity in a semiconductor

• Mössbauer effect in liquid crystals and biological systems

- Statistical Physics (including high polymers, superfluidity, and superconductivity)

• Study of superfluid Bose and Fermi systems using quantum field theory

• Renormalization group theory of critical phenomena

• Polymer physics including studies of molecular weight distribution, equation of state, and phase transitions

- Plasma Physics and Astrophysics

• Plasma waves

• Transport phenomena

• Plasma confinement and instability

• Solar flares

• Magnetospheric and solar winds

- General Relativity

• Theory of gravitation and its cosmological implications

• Hawking radiation from horizons

- Quantum Optics
 - . Multiphoton processes
- Chemical Physics

Applications of quantum theory based on the Hartree-Fock method and modifications of it are being made to problems involving large molecules in biophysical systems.

- System Physics

Work on the solution of the nonlinear Volterra system described by the Lotka Volterra equations is being undertaken.

EXPERIMENTAL PHYSICS

- Low Temperature Physics

- . Superconductivity
 - Determination of energy gap in superconductors using ultrasonic pulse echo technique,
 - Studies of the intermediate and mixed states of superconductors,
 - Studies on the effect of doping, strain, and pulse amplitudes in superconductors,
 - Order parameter fluctuations in thin Type I superconductors,
 - Dislocation resonance in superconductors,
 - Thermal properties of superconductors,
 - Tunneling effect in superconductors and normal metals,
 - Surface impedance measurements in superconductors and normal metals; penetration depth in superconductors.

- . Transport Properties

- Metals, semimetals, semiconductors, and superconductors,
- Thin films.
- . Thermoelectric Power of single crystal of iron whiskers in the range 4.2 to 300 K
- . Extension of Josephson effect, production and detection of microwaves
- . Band structure of solids
- . Ultra low temperatures
 - Extension of present lowest temperature of 1.2 K to millidegree Kelvin range to study superfluidity of ^3He , Kondo effect in dilute magnetic alloys, range of superconducting transition temperature.

- Microwave, Laser, and Semiconductor Physics

- . Microwave antennas

- Multiband antennas used in radar,
- Dielectric rod antennas,
- Combination of dielectric and metallic wave guide structure,
- Studies of grating structure in X and L band,
- Microstrip antennas,
- Development of monopulse radar receiver.

. Ferrites

Magneto microwave Kerr effects of ferrites at X and K-bands (proposed K-band measurements will use Mg-Mn, Li and garnets).

. Microwave Spectroscopy

Investigations such as collision broadening have been carried on for the last fifteen years; it is proposed to set up a double resonant spectrograph using a phase locked system.

. Lasers

A laboratory has been set up with a ruby laser and multiphoton processes in crystals have been investigated (as already mentioned). Crystal growing facilities are being developed.

. Solar Cells

Investigations are under way to study solar cells under transient and partial illumination.

- Nuclear Physics and Mössbauer Effect

. Nuclear structure studies

Nuclear structure studies have been carried out for many years; plans are underway to continue the studies using the new variable energy cyclotron at Calcutta.

. Nuclear Solid State Physics

- Hyperfine structure studies using integral and time-differential perturbed angular correlations in rare-earths and liquid crystals,
- Nuclear charge radii and liquid crystal studies using Mössbauer techniques,
- Phase transitions and intermolecular interactions in liquid crystals through positron annihilation lifetimes and Doppler broadening measurements,
- Studies on biological systems using NMR and other techniques.

. Mössbauer Effect

Studies are mainly concerned with the application of the Mössbauer effect to solid state physics. Temperatures are available for these studies from liquid nitrogen to 1000 K. The work so far has been directed to measuring hyperfine interactions in various iron compounds. In the future, the Mössbauer effect will be used to study the structural properties of thin films and to investigate liquid crystals.

- High Pressure and High Polymer Physics

The experimental activities of this group were started in 1972 under the auspices of the University Grants Commission and the United Nations Development Program. Facilities for the generation of pressures up to 10 kilobars have been developed (plans for extending this to 30 kilobars are under way). A high pressure differential thermal analysis system for the study of phase transitions has also been developed. It is now possible to carry out PVT measurements up to 10 kilobars. Other facilities such as differential scanning calorimeter, polarizing microscope for birefringence measurements, capacitance bridge for dielectric measurements, and diamond anvil press for pressures up to 100 kilobars over small volumes are available. So far, the work has been carried out in the following areas:

- crystallization kinetics,
- polymerization and degradation kinetics,
- equation of state,
- phase transition, and
- dielectric and ultrasonic relaxation studies.

Future plans include the extension of PVT measurements up to 30 kilobars. It is hoped that facilities will be available for measuring the viscosity of fluids as a function of temperature up to 30 kilobars in order to apply the results to the hydrostatic extrusion of metals, etc.

- Ionospheric Physics

Ionospheric research started in the department about fifteen years ago under the leadership of C. S. G. K. Setty. He is still the senior faculty member in this activity. A center known as the Ionosphere Research Center (administratively within the Department of Physics and Astrophysics) with 2200 square feet of laboratory space on a twelve acre site outside Delhi was inaugurated in February of 1973. Aerial installations of 100 feet high masts and several folded dipole antennas are in place. The funds for establishing the center came almost completely from the United States. A flood in 1978 gave rise to some problems, but much more serious, in January of 1980, a dike on the Yamuna River broke and the center was severely damaged. At the time of my visit to the center, it still showed great disrepair. The University Grants Commission is providing funds to help restore the damaged center. Workers at the center were very discouraged at the time of my visit. At the time of the founding of the center, ionospheric work was being carried out on the Campus with small-scale antennas. Electron-molecule collision frequencies were being determined in the ionosphere and such work is still going on. The center has been involved in cross modulation gyromagnetic experiments in which a powerful pulse at one frequency is transmitted at one time, and a medium power pulse at another frequency and time and the cross modulation is detected giving such parameters as the electron concentration, collision frequency, and indirectly temperatures in the interacting regions. This is a ground-based method for studying the low electron densities in the D layer and can provide information about ionospheric heights as low as 65 km. The two frequencies being used are 1.75 MHz and 2.13 MHz. Modelling of the F-region and the sporadic E layer have been carried out. The center first used ionosondes to study gravity waves in the atmosphere. Future activities will emphasize the interests of the international cooperative Middle Atmosphere

Program (MAP). Recent observations in the Delhi laboratory on the regular "sporadic D-layer" echos from 96 km height observed at 2.13 MHz and the observations of the D-region "ledge" about 86 km will be studied in the next five years. The titles of some recent publications follow:

- "Mid-latitude meridional neutral winds: a comparison of radar observations with those derived from MSIS model,"
- "The variation of electron collision frequency in the ionosphere,"
- "Effects of wind and electric field on electron energy distribution function at high latitude,"
- "On Joule heating of the equatorial electrojet E-region,"
- "Study of medium scale travelling ionospheric disturbances using multistation ATS-6 Faraday rotation data,"
- "Energy transfer rates of electrons in the ionosphere,"
- "Collisions and transport of electrons in the ionosphere."

- X-Ray Crystallography

Work has been primarily in crystal growth and in study of imperfections in crystals, particularly in regard to the growth of polytypes. Polytypism is still an unsolved problem. Techniques include x-ray diffraction and optical techniques. X-rays with energy up to 60 kV are available.

- High Energy Physics

The high energy physics group is one of the oldest experimental groups in the department. Work has been carried out on the properties of K-mesons, and hyperons, and hyperfragments. High energy interactions from 22.8 GeV up to 400 GeV have been investigated. Clusterization has been studied in cosmic ray interactions and clusters have been found to have a dynamical existence at different primary energies. Properties of clusters is a continuing subject for study. During the past years, the group's interest has gradually shifted from emulsion to bubble chamber techniques. The group is involved in a collaborative effort with other Indian institutions to study ultra-heavy cosmic ray nuclei and high energy interactions at energies greater than 20 TeV using the Long Duration Exposure facility of NASA.

- Spectroscopy

The effect of solvent on fluorescence polarization and the possibility of using fluorescence polarization spectra to distinguish between competing processes giving overlapping fluorescence bands has been the subject of work in the last few years. Plans are to investigate the relation between the structural stability of the molecule and fluorescence.

- Dielectrics

Work is mainly concentrated on electrical behavior (low frequency ac conductivity, dc conductivity, etc.) of transition metal ion phosphate glasses. Surface effects in single crystals and polycrystalline powders of ferroelectrics have been studied by observations of their low frequency electrical behavior. It is planned to expand the studies to measurements of dielectric permittivity and magnetic permeability of ferrites in the microwave region. Ferroelectric studies are directed toward understanding devices such as FETs and infrared detectors. Amorphous semiconductor studies will be extended to choicogeneide glasses.

- Semiconductor Devices

Work is going on in electrical transport properties of semiconductors and on microwave semiconductor devices and solar cells. Studies will be made of heavily doped II-VI and II-VI semiconductors.

- Astrophysical Observatory

Astrophysics in the department has been a subject of research since 1935. By the mid-50s emphasis was also placed on plasma astrophysics, solar-terrestrial physics, and radio astronomy. Currently, a six inch refracting telescope is being operated and solar flare work is being pursued. Plans are underway to construct a 16 inch reflector having spectroscopic attachments.

OTHER COMMENTS

In a document prepared in 1981 by the Physics Department on the development of teaching and research for the next five years, it was stated that research activities are being hampered by lack of resources, space, an up to date library, other ancillary facilities such as photocopiers, and electric typewriters.

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CONFERENCE ON LASER-INDUCED PROCESSES IN BIOLOGICAL MOLECULES

Masamichi Tsuboi

The conference was held on 6-8 July 1981 at Stanford University under the sponsorship of the Office of Naval Research. As members of the organizing committee, Professor M. Weissbluth, Applied Physics, Stanford University and Professor R. Picora, Chemistry, Stanford University, proposed discussions in the following two categories:

- experiment in which laser radiation is employed as a diagnostic tool to probe various properties of biological molecules;
- work in which laser radiation acts as an influence to induce some alteration in the behavior of a biological molecule.

The proposal was quite timely, and as was expected, very active and profitable discussions emerged from every session. There were about 50 participants. Among them were two Italians, (Drs. R. Cubeddu and A. Andreoni), two Japanese, (Drs. K. Yoshihara and M. Tsuboi), one scientist from England (Dr. J. T. Richards), one Canadian (Dr. P. Carey) and 15 to 20 U.S. investigators from institutions other than Stanford University. Altogether 20 talks were presented, of which about half may be classified in the first category given above, and remaining half seemed to belong to the second category. In many of the first category studies, however, pursuits of laser-induced processes were involved, and in many of the second category studies, lasers were used not only for inducing some alterations but also for probing them.

A laser-induced fluorescence measurement is known to be a sensitive method of quantitative analysis in general. Dr. K. Milby of Professor R. N. Zare's group at Stanford University reported a newly-designed, extremely sensitive laser fluorometry, which involves their "sandwich immunoassay" and "enzymatic amplification." Here, the target molecule is sandwiched by two antibody molecules, one of which is bound to a solid phase and the other produces continuously fluorescent molecules through an enzymatic reaction.

What Professor D. F. Nicoli (University of California, Santa Barbara) reported, on the other hand, was a competitive mode immunoassay, in which the amount of a tagged molecule (A^*) bound to an antibody was measured by observing "number fluctuation." The number fluctuation in a small volume is greatly different for A^* bound to the antibody from that for free A^* . Professor M. Morales' group (University of San Francisco) applied a fluctuation analysis to a muscle function. A correlation of the time of ATPase activity and rotational motion of the myosin head S1 has been examined.

Right after a pulse laser excitation, fluorescence is in general polarized. The polarization changes as a function of time and this gives a useful piece of information on the rate of rotational motion of the fluorophore or of a macromolecule to which the fluorophore is fixed. Dr. D. P. Millar (California Institute of Technology) reported their application of this technique to DNA and synthetic polynucleotides, and the present writer reported their application to nucleosome core particles and to a linker DNA in a chromatin.

Such a rotational diffusion coefficient of macromolecule can also be derived from a light scattering experiment, as Drs. K. Zero and R. Pecora (Stanford University) reported for their case of myosine molecule. A light scattering measurement can also be used for determining the diffusion coefficient of the translational Brownian motion of a macromolecule. Dr. D. S. Cannell (University of California, Santa Barbara) found that

oxyhemoglobin has slightly but appreciably greater diffusion coefficient than deoxyhemoglobin.

Resonance-enhanced laser-Raman spectroscopy is now widely used. If an ingenious chemical device is combined with this method, it is even more useful. Dr. P. Carey (NRC, Ottawa) used a thioester as a substrate analogue of papain, and succeeded in recording the Raman spectrum of an intermediate of the enzyme reaction. Only the intermediate here has an absorption band at 410 nm and the Raman scattering was excited with a 441.6 nm laser beam. Drs. R. Mathies and M. Braiman (University of California, Berkeley), on the other hand, found that the deuteration of a retinal chromophore at position-15 reveals differences in the character of the fingerprint vibrations in the 13-cis and all-trans isomers, which are otherwise similar. By the use of resonance Raman spectrum (413 nm excitation), they could conclude that the primary photochemical process in bacteriorhodopsin is an all-trans to 13-cis isomerization.

Retinal chromophore in the visual system is one of the most important subjects concerning the second category students. The light absorbing molecule in all known visual systems is 11-cis retinal. Dr. W. Carlsen in collaboration with Professors L. Stryer and A. Siegman (Stanford University) illuminated rhodopsin samples with 30-picosecond laser pulses of intensity just sufficient to cause moderate photolysis. These laser pulses also produce Raman scattering, and by examining it they showed that isomerization from 11-cis to a distorted all-trans form takes place within picoseconds of absorption of a photon.

Chloroplast is another important subject of the second category studies. Professor K. Yoshihara (Institute for Molecular Science, Okazaki, Japan) talked of their investigation on the picosecond transient behavior of highly enriched reaction-center particles prepared from spinach chloroplast. He showed that the incident light is absorbed by antenna chlorophylls, and the excitation is transferred to "P700"; subsequently P700 is oxidized to P700⁺. Kinetic analysis showed that the charge separation proceeds with a time constant of about 30 psec.

Recently, there has been encouraging scientific news regarding the selective damage of tumor cells that seem to be caused by laser irradiation on animal tissue in the presence of a dye. At the conference, there were two presentations in connection with this news, namely those by Professor R. Cubeddu (University of Milan) and by Professor J. G. Parker (Johns Hopkins University); both dealt with quite fundamental aspects of the phenomenon. The process seemed to involve;

- a laser excitation (e.g., at 532 nm) of a dye (e.g., hematoporphyrin) on to the first excited singlet (S_1) state,
- a deactivation of S_1 either collisionally, radiatively, or by intersystem crossing to the triplet metastable (T_O) state,
- spin conserving energy transfer from the dye triplet (T_O) to the triplet electronic state of oxygen 3O_2 to form the singlet 1O_2 , and
- cell necrosis caused by 1O_2 .

The reversible photolysis of carboxyhemoglobin (HbCO) has been the subject of a number of investigators. Dr. J. T. Richard (Salford University) used nanosecond laser photolysis and showed that following photolysis of aqueous solutions of HbCo a geminate recombination takes place on a nanosecond time scale. The extent of this fast recombination increased with lowering temperature.

Professor G. D. Hickman talked on the bioluminescence. This is the emission of light

from living organisms. Dinoflagellates are microscopic one-celled organisms and are commonly believed to be the major source of oceanic luminescence. He used a pulsed tunable dye laser to stimulate them. It was found that the higher the laser excitation energy (at 585 nm, for example), the more intense the bioluminescence. The response was found to be much greater for the first pulse than that for the succeeding pulses.

Dr. C. Dismukes (Princeton University) talked about how plants oxidize water to produce O₂. This was an electron paramagnetic resonance study of a Mn-containing protein which catalyzes the photolysis of water. Dr. S. Boxer (Stanford University) gave two lectures with the titles: "Laser-CIDNP spectroscopy to probe protein surface topology," and "The effects of very large magnetic fields on primary processes in photosynthesis."

Finally, a brief paragraph will be given here for what the present writer presented at the meeting. The subject was chromatin, which consists of nucleosome core particles, linker DNA, H1 histones, and some nonhistone proteins. The sources of the samples were calf thymus and chicken erythrocyte (the preparations were made in collaboration with Drs. K. Iso, K. Watanabe, and M. Zama). For these samples, fluorescence lifetime measurements were made with pulsed lasers. The fluorophores used are:

- tyrosine residues involved in the histone octamer core,
- N-(3-pyrene) maleimide bound to H3 histone moieties, and
- ethidium bromide intercalated into DNA moiety.

A Raman spectroscopic examination was also conducted for a few chromatin and nucleosome preparations. These laser experiments were made in collaboration with Dr. Y. Nishimura, Mr. I. Ashikawa, and Mr. H. Haruyama. From the observed lifetime values, we can derive pieces of information on the micro-environments of the fluorophores, rates of energy transfers (from tyrosine to DNA bases, for example), and rates of fluorophore rotations (which may be related to the overall rotation of a nucleosome core particle, or flexibility of DNA chain, or micro-Brownian motion of a fluorophore).

THE JAPANESE APPROACH TO RESEARCH IN MOLECULAR BEAM EPITAXY AND SEMICONDUCTOR MATERIALS PREPARATION

Murray Gershenson

INTRODUCTION

During the summer of 1981, I spent four weeks visiting molecular beam epitaxy (MBE) facilities such as industrial research and development laboratories, university laboratories, and government laboratories in Japan. In the following, I would like to present my observations, evaluations, and comments on Japan's advance in molecular beam epitaxy (PART A), as well as a few personal observations on their methods of approaching science and technology (PART B).

PART A: MOLECULAR BEAM EPITAXY (MBE)

Here in the United States, MBE appeared almost full-grown as a single quantum jump. Arthur used molecular beam sources to study the surface chemistry and physics at a GaAs-vacuum interface under UHV conditions. Cho extended that technique to the growth of GaAs and full-fledged MBE, with multiple sources in a LN₂ shroud with quadrupole mass spectrometry and HEED became the norm for MBE at a very early stage. The only real development since was the air lock.

In Japan, MBE started slowly, usually with Si, and then evolved in several different directions, of which MBE was only one. The evolution consisted of small steps. This was partly because it was (and still is) difficult to get a large equipment grant as a single chunk of money. The availability of good interchangeable vacuum components from Anelva (now called Neva-NEC plus Varian) and Ulvac made the evolution in small steps easy. This evolution can be seen at universities, where the older machines have not been scrapped.

In the '50s and early '60s, United States Si technology was transferred to Japan. This included vacuum evaporators (10^{-7} Torr) for metallization. In the early '60s, ion beam techniques were being developed in the U.S. for two basic reasons. First, ion implantation would be a way to produce very special doping profiles for expensive devices, not as a replacement for diffusion processing which was satisfactory for the thicker, larger devices then being made. Second, ion beam techniques might be useful for growing exotic materials, e.g., preparing p-type CdS, which could not be made with existing, near equilibrium growth techniques. In the U.S., ion beam techniques quickly narrowed down to ion implantation, a method that became cost effective as a commercial doping process as the devices became smaller and smaller. Ion beam techniques for materials preparation almost vanished.

Not so in Japan. Materials preparation by ion beams lingered on, especially at universities. With the Japanese tendency to be thorough, to try everything even without a clear-cut scientific reason for doing so, they tried growing everything by ion beam techniques, Si, the III-V's and the II-VI's. Beam currents could not be made high enough for rapid growth, so they used evaporation methods and mixed neutral beams with ion beams, adding a mass spectrometer to measure the flux of neutrals. About ten years ago, this shotgun approach began to crystallize into several distinct areas: pure high energy ion implantation, plasma and reactive plasma growth, and MBE. However, MBE was left with the legacy of ion beam techniques, which is still a common mix today. Here, with interchangeable standard vacuum components readily available, diffusion pumps were replaced with ion pumps; the simple evaporation sources became effusion cells housed in a LN cooled flange. It was only the source flange that was not a standard catalogue item.

To them, even now, MBE is a very flexible technique. Ion beams, LEED, ESCA, etc., can be added or removed at the drop of a hat.

To us, MBE is an expensive, exotic technique, reserved for growing structures or materials which cannot be made by any other standard method. To the Japanese, MBE is becoming an accepted standard method of semiconductor preparation. They believe MBE will become a cost effective production technique. As a result, they are working on growing large area display structures and on growing large area (one sun) solar cell structures.

I saw, or was told about, 70 MBE machines. Half of these were truly MBE by anyone's standards. The other half could or could not be considered MBE. These were mostly Si systems. My original definition of MBE ruled out diffusion pumps. However, seeing diffusion pumped systems with lots of LN₂ trapping operating below 10⁻¹⁰ torr (even in the commercial Vacuum Generators system) forced me to change my definition of UHV to mean less than 10⁻⁹ Torr. If free evaporation of Si from an e-beam heated open hearth is not MBE, does placing a collimating plate and shutter in the beam make it MBE? Our effusion cells are not true Knudsen cells anyway. Consider the systems which use an ion beam for one of the constituents, or a partially ionized beam. How should they be classified? I gave up trying to define MBE. Thus, there are at least 35 true MBE systems discussed in this report and about 35 others (mostly for Si) that may or may not be MBE.

I saw very few standard, commercial MBE systems: two from Varian, two from Vacuum Generators and six from Anelva, but none from River or from PHI. The rest of them are homemade, built up from a bell jar and source flange made for them by Anelva or Ulvac. The pumps are usually ion pump/Ti sublimator combinations (400-800 l/sec). Newer systems are incorporating turbomolecular pumps and cryopumps and some use diffusion pumps (as the Vacuum Generators system) with lots of cryopanels. The latter are, of course, useful for pumping H₂, allowing the use of AsH₃ and metal-organics. Some of the older systems have no air locks; but most of them use an entry chamber where the sample is put onto a rod and stays there as the valve to the growth chamber is opened and the rod inserted. This requires a Cu bellows which is always exposed during growth. Outgassing and small leaks are common here; hence Al is difficult to handle in such a system. All the newer units have an air lock plus a true sample transfer system, either via bellows or via magnetic manipulation. In either case, the entry chamber is valved off from the growth chamber before growth commences. I saw a few three chamber systems, but this was the exception. Anywhere from one to eight radiation shielded effusion cells are mounted in a source flange. In the older units these are water cooled; in the newer units they are surrounded by LN₂. BN crucibles are used extensively. Most of the systems have, or have provisions for, one or two e-beam hearths, usually water cooled. This, of course, is the basis for the Si machines. Only a few of the systems I saw have cryoshrouding around the sample. All the systems had a quad and usually a separate nude ion gauge as a flux monitor. Most had HEED or MEED or very high energy (50 keV) HEED, or LEED. A few had Auger (with sputter profiling), ESCA or UPS. Sample heating is often accomplished with a free hanging sample heated resistively or by radiation from a free hanging heater spiral behind the sample. Here, a thermocouple contacts the sample directly, but more often, an optical pyrometer is used. These simple techniques work well for substrate temperatures above 800°, but temperature uniformity is a problem. Low energy ion beams (<1000 eV, usually ~100 eV) are very common, as noted above, especially for growing Si from a partially ionized beam (partially ionizing the neutral beam) or for doping with elements with very low sticking coefficient, e.g., Zn for GaAs.

To the Japanese, MBE is a tool for the future, both for research and development and for production, and their involvement with this technique is obviously growing.

INDUSTRIAL RESEARCH AND DEVELOPMENT (R&D) LABORATORY VISITS

THE ELECTRICAL COMMUNICATIONS LABORATORIES OF NTT (MUSASHINO)

Nippon Telephone and Telegraph (NTT), like American Telephone and Telegraph (ATT) here, runs the basic communications network in Japan, but unlike ATT, it does not have a major manufacturing subsidiary like Western Electric. Instead, it purchases its equipment from Nippon Electric Company (NEC), Fujitsu, etc. I saw their research laboratories at Musashino, but I did not see their laboratories at Ibaraki, where there is also some MBE work. The sixth section of the Research Division at Musashino, under Dr. Y. Suemune does research on optical devices:

- growth of substrates (InP, GaSb, PbSnTe),
- permanent optical writing for laser video discs (heating metal oxides, infrared photochromics),
- semiconductor lasers and integrated amplifiers and modulators,
- nonlinear interactions (laser bistabilities, switching and pulsation),
- new materials and technologies (the MBE grown superlattice, zero gravity PbSnTe growth in space).

For the MBE work, Dr. Hiroshi Okamoto, who has worked with MBE for four years was my guide. They have three MBE systems. The first was built to their design by Anelva and became the prototype for Anelva's first generation machines. The second and third are standard Anelva Model 830 first generation systems. In the first, the sample is held on a rod which is inserted into the growth chamber after entry chamber pump-down. The sample is not transferred; the valve to the entry chamber remains open during growth. Rod movement depends on a bellows in the entry chamber with atmospheric pressure on the outside. The other two, which can accommodate 1½" substrates, rely on transfer, magnetically coupled movement, and bayonet-type transfer clips, so that the entry chamber can be valved off after transfer. These are all one chamber systems plus load lock. The latter systems contain cryoshrouding around the sample, the former only around the sources. The first two systems contain four vertical crucibles, the third, eight crucibles around a center line 45° from the horizontal. They all have quads and HEED, but no Auger (there is no separate analytic chamber). Because of poor thermocouple contact with the sample heating block, an IR pyrometer is used in one of the systems. The systems contain many spare ports. Pumping of the growth chamber is by a 400 l/s ion pump plus Ti sublimator.

The crucibles are simple test tube shaped BN crucibles surrounded by a tungsten spiral heater. They use Al in two of the systems. To prevent the Al crawling up the crucible and out onto the Ta radiation shield, they place a graphite cap-aperture atop and in contact with the crucible. Al does not wet the graphite, it does not condense on the graphite and there is no evidence for the formation of Al_4C_3 .

The use a red P_4 source for their InP work. After a run, when the cryoshroud is warmed, the background pressure goes up to 10^{-3} Torr (P_4 plus H_2O). Like Kroemer at University of California, Santa Barbara, they also have As and GaAs coating the inside of the chamber, but Kroemer uses a P_2 source-GaP, not a P_4 source-red phosphorus. After each run, they valve off the ion pump, turn on a cryopump through an auxiliary port and bake the system. Next morning they valve off the cryopump, warm it up, and transfer the phosphorus to a sorption pump.

Their work on fabricating structures, microfabrication, and device characteristics is of very high caliber, but I saw no indication of any real studies of the physics of the device.

Dr. H. Asahi showed me his work on the long wavelength InGaAs/InP DH laser for optical fiber systems. A (100) InP substrate is cleaned by flash heating to 480° for one minute under P₄. A 1 μm n-type (~10¹⁸, Sn, 450°) buffer layer of InP is grown next. Then the sample is cooled; next the P₄ source is cooled. Then the As source is heated. Finally, the sample is reheated to 480° and a .2-.4 μm thick active layer of lattice-matched InGaAs (n-type 10¹⁶-10¹⁷) is grown. They use an InGa mixed source. The In comes off first; hence, in time, the melt becomes rich in Ga. Thus, they use a second source of pure In to fine tune the ratio. The quad works for this, provided the As flux is constant. Next, a 1 μm p-type InP cladding layer is grown. Mn is used as the dopant, but its behavior is strange. The hole concentration increases with Mn cell temperature, reaches a maximum (2 × 10¹⁸), then decreases. Auger analysis shows that the Mn concentration keeps increasing while the hole density decreases. (At high P₄ pressures, the doping is even less.) From Hall data, at low Mn fluxes (equivalent gauge pressure 7 × 10⁻⁷ Torr) Mn is a shallow acceptor, .04 eV. However, at the higher fluxes (2 × 10⁻⁶ Torr) Mn is a deep acceptor, .28 eV. Finally, a p-type InGaAs cap layer is grown to facilitate good ohmic contact and to make the upper surface clearly visible in SEM after cleaving. The photoluminescence of the active layer is a sharp peak at room temperature, but its efficiency is low. The efficiency can be increased a factor of 10 by annealing at 700°. A simple stripe geometry laser made from such a structure lases CW at 6°C. A buried channel active layer structure, made by etching a mesa right through the active layer and regrowing p-InP by LPE over the entire mesa surface lases at room temperature.

Dr. Okamoto showed me Ishibashi's work on GaAs/AlAs superlattices. He is trying to develop a visible laser to replace the He-Ne laser for video disc readout. His work is based on Holonyak, *et al.*'s MOCVD grown MQW structures and on Tsang's MBE grown structures. The layers are all n-type, Sn-doped (no p layer has yet been added for electrical injection) grown on semi-insulating (100) GaAs substrates, at 700° (using an IR pyrometer). The active layer (L_z) of GaAs is 20-160 Å thick and is grown at .4-.8 μm/hr. The barrier layer (L_b) of pure AlAs is 30-100 Å thick and is grown at .2-.7 μm/hr. 250 layers are grown (1.5-2.0 μm) using the quad in a multiplex mode to monitor both Ga and Al. By using a shadow mask, set relative to the Ga and Al impingement angles, a region containing only Ga, no Al, is obtained. From the measured profilometer step height, that of the total grown crystal height, and knowing how many layers were grown, both L_z and L_b are determined. A second method is based on rocking curve x-ray (400) diffraction measurements. The average Al content, L_b/(L_b+L_z) is obtained from the change in angle between the zeroth order MQW peak and the substrate peak (visible through the thin epilayer). A single (thick) layer of AlAs on GaAs was used to check this result. From the positions of the first order and second order MQW peaks the total period L_z+L_b is obtained. Thus, L_b and L_z can be deduced individually. This diffraction method agrees with the shadowing method to 10%. Room temperature photoluminescence (He-Ne excitation, no 77° or 4° K data) shows one peak, no LO replicas. The peak is narrower than that for pure GaAs due to the constant, step function density of states for these two-dimensionally confined carriers. The position of the peak (.70-.85 μm) corresponding to L_z (20-160 Å) is the energy in the active layer between the n = 1 conduction band level and the n = 1 valence band state. If the layers are heavily doped n-type (Sn, 2 - 5 × 10¹⁸), the peak moves to lower energies, opposite that of a Burstein-Moss shift. They have worked out a theory based on electron screening, that predicts a decrease of the effective bandgap. At low electron doping, simple quantum well theory is obeyed.

Naganuma has been working on the GaSb-AlSb superlattice. Here GaSb is the active layer and AlSb is the barrier layer. They are grown on (100) GaSb at 460°, GaSb at 1 μm/hour, AlSb at 0.5 μm/hour, at a Sb/Ga ratio of 4-8. They are doped n or p type (5-10 × 10¹⁷) with Te or Be. For thicker layers, the layers can be seen by SEM after cleaving. For

thinner layers, the x-ray diffraction technique described above is used. These check the shutter cycle to 5%. Typically, L_b (AlSb) is 40 Å and L_z (Ga Sb) is 40-200 Å, with a total of 250 layers grown. Photoluminescence (300°K, no low temperatures, He-Ne excitation) gives the $n = 1$ to $n = 1$ transition wavelength (1.7-1.3 μm) corresponding to L_z of 200-40 Å in detailed agreement with theory. However, for $L_z < 70$ Å the $n = 1$ level corresponding to the L conduction band minimum of GaSb falls below that corresponding to the Γ minimum. (The L-mass is high.) Here the linearity with L_z changes abruptly and the luminescence efficiency drops for this indirect system.

In addition to hearing about older MBE work on InSb and on the GaAsSb system, I was impressed by recent MOCVD work on the quaternaries InGaAsP and InAsSbP.

FUJITSU LABORATORIES

Fujitsu Laboratories is the research and development arm of Fujitsu, Ltd. Their base has been as a principal supplier of communications equipment to NTT. However, the world knows them by their computers. They are now the largest computer manufacturer in Japan. They have 34,000 employees. They market their large main frame units in the U.S. through Amdahl. They just formed TRW-Fujitsu to sell smaller office sized computers here. They also do device manufacturing in San Diego as Fujitsu Microelectronics. They have no fear of competing head-on with IBM, although their products are plug compatible. They now have 3,000 people working on software development.

Their hallmark is one, clever innovative extensions to technology of existing (usually new) science, rather than merely extensions of existing technology, although they do not really develop the science base themselves and two, rapid turnaround into production.

They were the first company to market the 64 K RAM (in 1978) and they are very strongly developing and marketing fast GaAs devices. From what I have seen, I would expect them to be one of the first out with the 257 K Si RAM advanced longwave optical communications systems and ultrafast GaAs devices, including the HEMT described below.

Their work is done by teams, who review their goals often and who take great pride in their accomplishments. An entire team may transfer to the factory for a while to help start up production.

My guides were Dr. T. Misugi, General Manager of Semiconductors, Dr. K. Dazai, Manager of the Optical Semiconductor Devices Laboratory, and Dr. S. Hiyamizu who is doing the MBE HEMT work. They were all very open, frank, and kind to me. I had heard Dr. Hiyamizu talk several weeks earlier at the Crystal Growth Conference in San Diego.

Their basic philosophy for optical communications systems is to go after both the short haul and the long haul systems. The short haul (<20 km) system is a low bit rate, but large volume business, for home cable TV and the like, using multimode fibers with 0.85 μm GaAs DH LED's (not lasers, to simplify degradation problems) and Si APD (or PIN) detectors. This system is basically ready to go. The long haul system (>20 km) a high bit rate, small volume business, mainly to NTT, will use single mode fibers (developed and manufactured here) and 1.3 μm InGaAsP/InP lasers with InGaAs APD detectors.

They are currently selling, for 0.85 μm , GaAs DH lasers and LED's (LPE grown) and Si APD and PIN detectors. For 1.3 μm they have on the market LPE grown InGaAsP LED's and Ge APD's. I saw InGaAsP lasers and InGaAs APD's, LPE grown, on accelerated life tests. These are now being transferred to production. In addition, they are making 1.7 μm

InGaAs emitters (LPE) and also $0.7 \mu m$ DH AlGaAs visible lasers (LPE) for video disc systems.

One of Fujitsu's great strengths, and they have become a leader in it, is in analog, high power and low noise, high frequency GaAs MESFET amplifiers as a replacement for the TWT. They cover 2-18 Ghz, with 1-20 W at 40% efficiency. Their current big sellers are four Ghz-10W and 12 Ghz-3W devices. They are now moving rapidly into GaAs logic chips. Their commercial GaAs FET's are grown by halide CVD, but, using N_2 , not H_2 , as the carrier gas.

With the ink hardly dry on the first paper to discuss modulation doping (the Japanese call it "selective doping"), they have built the first HEMT (high electron mobility transistor) based on this idea (the basic science has yet to be worked out in any detail), and they are counting on it as the next generation of fast GaAs devices. They talk about HEMT's as though they have been around for years. They know that with its low power dissipation and its ultra-fast switching delay times (17 ps measured at 77°K) it is a direct competitor with the Josephson junction. (They are also working on that.) From what I have seen and heard, I think they will have the HEMT on the market within a year or so, made in their brand new Varian Gen II MBE.

Because of the potential importance of the HEMT, I will describe it in some detail. In the basic modulation doped structure, an undoped (or very lightly doped n-type) GaAs layer is grown in contact with a donor-doped AlGaAs layer (leaving $\sim 100 \text{ \AA}$ of undoped AlGaAs near the interface). The electrons drop down the barrier wall into the GaAs conduction band, which then bends upward, away from the interface, so that the electrons are pinned against the interface forming a two-dimensional gas. If the AlGaAs layer is thin enough or only lightly doped it will be completely depleted. The electron gas in the GaAs, feeling no Coulombic forces from the distant ionized donors can now exhibit very high mobilities, especially at low temperatures, where the limiting lattice mobility is very high.

Hiyamizu and his co-workers have published six papers in the last year (one a month for the past four months in the *Japanese Journal of Applied Physics*) on the measured mobility in such a structure. At last account this was 8,600 (300°K), 117,000 (77°K) and $244,000 \text{ cm}^2/\text{v sec}$ (5°K) for a two dimensional carrier density of $5 \times 10^{11}/\text{cm}^2$. Altering the potential on the barrier layer (by a gate bias) relative to the GaAs layer, will alter the number of carriers confined, leading to an n-channel FET device. The enhancement mode HEMT structure is MBE grown at 580° on a (100) semi-insulating substrate. First, a $0.2 \mu m$ undoped GaAs layer is grown--the active layer. This is followed by 60 \AA of undoped $\text{Al}_x\text{Ga}_{1-x}\text{As}$, with $x = 0.26$ and then by $0.06 \mu m$ of Si-doped (7×10^{17}) n-type AlGaAs of the same composition. However, this is slowly graded to pure GaAs. Then, $0.05 \mu m$ of n (2×10^{18}) GaAs is grown. This will form the source and drain contacts. A channel is etched in this upper GaAs layer, $2 \mu m$ long by $300 \mu m$ wide. The gate contact (Au on Pt on Ti) is evaporated onto the exposed AlGaAs (graded to GaAs) in the moat. Ohmic source and drain contacts (Au on Au/Ge) are finally formed near the channel, but on top of the GaAs source and drain pads. The drain current exhibits a good square law dependence, $I_D = K(V_{GS}-V_T)^2$, with $gM = 193$ (300°K) and 409 (77°) m S/mm and $K = 34$ (300°) and 108 (77°) mA/V² for $V_{GS} = 0.7$ and $V_{DS} = 1.5$. The delay time, measured from a 27 stage ring oscillator is 56 ps at 300° and 17 ps at 77°. These switching speeds are five times faster than with standard GaAs MESFETS and 20 times faster than the best from Si technology.

This work was all done by an older MBE system. However, they recently (February 1971) acquired a brand new Varian Gen II (Serial No. 2) production machine (with MITI

money, I think; the HEMT is now a MITI supported project). They are turning out two or three HEMT wafers a day on this machine. They are planning to use this machine for production, although they told me that they were also trying to fabricate the structure by MOCVD. Irrespective of which technique wins out, it is obvious that they will be marketing the HEMT, perhaps as early as 1983.

Although the HEMT structure is an ideal geometry in which to study the physical properties of a two-dimensional confined electron gas, as far as I know, only a group at Osaka University (see below) have worked with these samples (Shubnikovde Haas oscillations).

In other work that they are doing, they are trying to use the native oxide on GaAs as a growth mask. 100 Å oxide layers are prepared by oxidizing the sample in O₂. After using photolithography to open holes, GaAs is grown by MBE. It grows normally in the holes, but on the oxide it grows as very high resistivity polycrystalline material.

Before getting deeply involved with the HEMT project, they were using their old MBE system to grow InGaAs on top of GaAs. InGaAs lattice matched to InP has a band gap that corresponds to 1.7 μm, too long for the ideal long wavelength fiber optics system. The ideal wavelength, 1.3 μm can be obtained in the quaternary system InGaAsP on InP. Their approach, however, was not to lattice match to InP, but to grow InGaAs on GaAs, slowly grading the composition until that corresponding to 1.3 μm was obtained. They tried grading linearly and in a series of steps. However, their best results were obtained by using the Matthews superlattice method of grading to terminate propagating dislocations. In this case about 5 μ of linearly graded material was required, and just before the final composition was reached the composition was stepped up and down rapidly a few times to grow the superlattice. I assume that this project was abandoned, either because InGaAsP on InP was now being grown by LPE in the factory, or because of the impact of the HEMT work, or both.

Their old MBE system was built for them by ULVAC four years ago. It is a one chamber system. The sample is not transferred, but stays on the sample rod inserted from an air lock separated from the outside world by a bellows. A hefty 800 l/s ion pump and Ti sublimator pump the chamber and a second ion pump is installed so that they can shut off the main pump during bakeout. The system can handle 1 x 2" substrates (by tilting them during insertion into the growth chamber). They have two, four crucible, LN₂ source units making a shallow angle from the horizontal and a separate crucible source assembly for As. Simple BN crucibles are used with pneumatic shutters. Their effusion cells are 10" from the substrate leading to uniform growth, but wasteful of source material. The sources need to be refilled often. A nude ion gauge near the substrate serves as a flux gauge. They have a wide beam sputter ion gun for cleaning, but it is rarely used. They have a Quad and Auger (but no ion sputtering for profiling). They had electron diffraction once, but the e-gun could not go above several kV, too low for seeing clear streak patterns; so they removed it. All their work here is done without HEED (or MEED). There is a small, simple pancake cryoshroud on the top of the chamber. The normal background pressure after bakeout is ~10⁻⁹ Torr. They say that this system is not good for Al, both because of the minimal amount of cryoshrouding and because of the Cu bellows on the entry chamber (always exposed during growth).

Their new Varian Gen II production machine was delivered in February and it worked right away without any major problems. Two of the BN Al crucibles cracked, ruining the furnaces. This, of course is a standard problem with Al. They now always idle the Al crucible just above the melting point and have had no problems since they started doing

that. They load six 2" (or 1 x 2") wafers at a time, and make three runs a day. All the work is on the HEMT structure. They may use this machine for production, unless the MOCVD work pans out.

TOSHIBA RESEARCH AND DEVELOPMENT CENTER

Toshiba is the General Electric of Japan. Starting with incandescent lamps in 1880, they now market a very diversified line of consumer and industrial products from computers, TV's, and heavy machinery to semiconductors, with worldwide manufacturing facilities, including a semiconductor line in Sunnyvale.

M. Miyao of the administrative staff was my guide. I met Dr. K. Nagai, the Director of the R&D Center and Dr. Y. Takeishi, the Deputy Director, whom I had known at Bell Laboratories 20 years ago. In addition, I met Dr. K. Maeda who is now in charge of Toshiba's electron tube plant. He had worked with me at Bell for about two years.

Toshiba does no MBE work. I saw only their R&D effort in optical devices. Bulk crystal growth included LEC growth of GaP as substrates for GaP LED's and Czochralski growth of LiTaO₃ for SAW devices for TV IF filters. Toshiba has been very strong on GaP LED's, both red (Zn,O) and green (N). These are firmly entrenched in the factory. I saw a 64 x 64 element hybrid flat LED display. Each element consisted of one red and one green GaP LED and the current ratio between the two could be set from the outside. Thus, all colors but blue could be produced. As an advertising display it looked good, but it must be relatively expensive. I saw lasers and LED's (GaAs, InGaAsP, LPE grown). They are getting into the fiber optics business. They are pushing the Si CCD camera very hard, hoping to capture that market, especially the rapidly developing consumer market. In displays, they probably dominate the world market in CRT's at present, and they see no near-term challenge to the CRT. Finally, I saw some beautiful MOCVD work in GaAs by Dr. T. Nakanishi (reported at the Ajaccio Conference, last spring). I know they work on GaAs FET devices but I did not see any of that, just some GaAs Hall Effect devices.

SONY RESEARCH CENTER

It was Sony, of course, which started Japan down the high technology electronics road, with its transistor radios of the fifties. Unlike the other companies I saw, Sony's business is still confined to consumer video and audio products, no computers, communications systems, heavy machinery, etc. Their research center (200 engineers, 11 Ph.D.'s) is very product oriented. They have established leadership in consumer electronics (Trinitron picture tube, Betamax VCR) and they intend to keep it. They have strong R&D efforts in magnetic materials for tape and tape heads, in phosphors for TV color picture tubes, and in Si technology for CCD's for TV cameras, as a natural extension for video recorders for the home.

Their CCD camera uses prisms and filters to separate three color images, with a CCD for each. To avoid inactive pixel elements they did a lot of work on defects in Si, using EBIC measurements, etc., to detect stacking faults and other defects. Their devices now have nearly zero defects, and the team that developed them is now on temporary loan to the factory, helping to set up the production line. They will return when their work is finished.

Video disc recording and playback systems are now a major part of their work. Using digital techniques, they can store an hour of video information on a 3" disc. Its consequences for audio storage and the replacement of LP records are obvious. Readout is

by a 0.75 μm emitting DH AlGaAs laser. They were really aiming for 0.70 μm , but laser threshold was too high for such Al-rich active layers. As it is, they use 14% Al.

Their approach to the lasers is through CVD. I saw a room full of microprocessor controlled, homemade, CVD systems, two of which were MOCVD, reacting Me_3Ga and Me_3Al with AsH_3 on a 3" GaAs substrate resting on an RF heated graphite susceptor. The MOCVD results are excellent. Paralleling the Rockwell work in this country, they can easily produce 100 \AA uniform layers. They claim that the best MO sources (they have tried many) come from Sumitomo.

Their approach to lasers is twofold. The 0.75 μm lasers are grown on 2° off (100) GaAs substrates. H_2Se and Et_2Zn are the dopants. The active layer is 0.1 μm thick and is p-type; 5×10^{17} . The upper contact is a stripe geometry, either over an oxide mask, or by self-aligned proton bombardment over a metal strip contact. They have also been working on a vee-groove laser, which depends on a quirk of nature for its implementation. Currently, it uses pure GaAs for the active layer yielding a 0.87 μm emitter. A (111) vee-groove is first etched into a (100) substrate. Then a standard DH laser structure is grown, n (H_2Se) AlGaAs, GaAs, AlGaAs. Part way through the upper AlGaAs layer, the dopant is switched from S to Zn (Et_2Zn). The Zn diffuses through the AlGaAs, but stops at the AlGaAs-GaAs interface. So the p-n junction coincides with the heterojunction. Lasing occurs only in the active layer in the groove--one circular spot in the near-field pattern, with a threshold of 15 mA at room temperature and a differential quantum efficiency of 65%.

My hosts at Sony were Dr. M. Kikuchi, their Director, whom I have known for many years and Dr. N. Watanabe, the Deputy Director and head of their semiconductor research laboratory. As noted earlier, Kikuchi is an astute observer of the differences in the development of technology between Japan and the West, and we spent much time discussing this topic. Sony has no MBE work.

NIPPON ELECTRIC COMPANY CENTRAL RESEARCH LABORATORIES (NEC)

NEC is a huge company, 60,000 employees, 4,000 in R&D. They are the second (or third) largest semiconductor producer in the world, behind Texas Instruments (and either ahead or behind Motorola, depending on the current exchange rate for yen). Yet, only 20% of their business is in semiconductors. Their mainstays are consumer products (TV, VCR, audio, air conditioners, etc.), computers and communications systems. They are one of the largest suppliers to NTT. They are currently producing GaAs laser based fiber optics communications systems for NTT. Anelva vacuum is one of their subsidiaries.

Much of their R&D work is scattered among their plants. In their Basic Technology Research Laboratories (Dr. S. Asanabe, Manager), I saw the Fundamental Research Laboratories. (Here I met an old friend, Dr. I. Hayashi, co-inventor of the DH laser while he was at Bell Laboratories. Here he is the roving liaison scientist, moving from group to group, collecting and disseminating ideas, helping to establish attainable goals, an indispensable job in this setting. In addition, I met Drs. H. Watanabe and J. Matsui.) I also saw the Electron Devices Laboratory (Dr. Y. Takayama, Manager and Drs. T. Furutsuka and K. Ohata) and the Ultra-LSI Research Laboratory (Dr. O. Shinoda, Manager, and Dr. Y. Okuto, whom I knew quite well when he was working towards his Ph.D. at USC).

GaAs DH lasers are firmly set in the factory and there is little research left here in the R&D laboratories. In optical devices, the very large research effort is in InGaAsP/InP quaternary LED's (mostly), but also lasers for the long wavelength 1.3 μm fiber optics

systems. LPE grown devices are now in the factory. The push here is in VPE. The (100) InP substrates are grown by LEC. That is also in the factory. I saw a bank of at least eight completely automated CVD systems. Two of them were MOCVD, the others hot-wall halide VPE reactors. Their microprocessor controlled halide systems are based on a 3-4" diameter horizontal quartz reactor tube. It is divided in half by a horizontal quartz partition. The upper half is again divided in half by a vertical partition. In and Ga boats are inserted into the two upper chambers, and only an In boat in the lower chamber. In operation, the substrate is held on a quartz plate holder with In (as for MBE substrates) with a thermocouple close behind. While purging the system, the substrate holder is inserted through a rubber closure on the tail end of the tube onto a motor driven manipulator, and positioned in the lower chamber. H₂, then PH₃ is turned on, then a hot clam-shell furnace closes over the tube. When the temperature is up to steady-state, controlled flows of HCl are started over both the Ga and In boats in their respective chambers, as well as PH₃ and AsH₃. When the first InP layer is grown, the manipulator then pulls the substrate back, raises it, and inserts it in the upper chamber just beyond the edge of the divided region for InGaAsP growth. Growth is controlled by the total HCl mass flow (the conversion of HCl to InCl is 98%) and H₂Se and Et₂Zn are the dopants. The standard DH structure for LED's or lasers is a (100) n-InP substrate, an n InP buffer confining layer, a ~0.1 μm undoped GaInAsP active layer, a p InP confining layer and a p InGaAsP cap layer, the latter to facilitate ohmic contact.

They have also made InP/InGaAsP superlattices by rotating the substrate on an eccentric crank between the upper (InGaAsP) and lower (InP) chambers. Superlattice layers down to 100 Å have been grown with 10 Å step definition. This is deduced from x-ray diffraction rocking curves where up to four sharp orders are seen for the superlattice diffraction. This is confirmed by SIMS.

Single layers of InGaAsP grown on (100) InP are tetragonally distorted. (100) type x-ray diffraction measures the lattice constant of the layer normal to the substrate interface, but other Bragg reflection planes, lying at an angle to the substrate plane, measure a combination of this and the lateral lattice constant. From such measurements, the two tetragonal lattice parameters can be obtained. The lateral parameter always matches that of the InP substrate to which it was intentionally matched. The perpendicular parameter is slightly larger (~0.5%). Computer aided modeling of the structure to fit the shapes of the diffraction peaks, seems to indicate that the InGaAsP is graded in steps as one moves away from the interface, but these are not steps in composition, but are rather due to ordering in the alloy. This is nice science.

As found by others, they also note that the light output for LED's is sublinear in injection current, unlike GaAs emitters, and they also conclude that because of the lower bandgap of InGaAsP, band-to-band Auger nonradiative recombination is a fundamental limitation on the efficiency at high current densities. For an LED this can be minimized by widening the active layer, lowering the injected carrier concentrations. However, for a laser, this would also raise the threshold.

They have already given much thought to degradation in InGaAsP light emitters. Although they observe threading dislocations in the active layer, these do not climb during operation as they would for GaAs DH lasers. Thus, no dark line defects develop. Dr. Hayashi, with much experience with degradation in GaAs, has many thoughts on specific degradation mechanisms.

NEC is heavily committed to fast GaAs MESFET devices, many with 1-2 μm gates already in the factory, grown by halide (AsCl₃) VPE. In the R&D laboratories, I saw

discrete amplifiers being developed, both low noise (to 20 Ghz) and high power (4-12 Ghz). For both, clever manipulation of the geometry of the channel between the source and the gate reduces the source resistance, or lowers the field (to reduce the breakdown voltage). I.C. development is under way with simple analog circuits and with simple digital circuits (e.g., frequency dividers), the latter, a first step towards the development of a GaAs monolithic LSI technology. I also saw enhancement mode InP MISFET devices with SiO_2 as the insulator.

I saw some clever device physics experiments (Dr. Okuto) where the electric field dependence of the electron velocity in Si could be deduced from appropriate measurements on standard MOS/SOS devices. Also in Si, I saw CCD work going on and aimed for the home video TV camera market.

NEC has no ongoing MBE work, but I saw the remains of an old "semi" MBE system (10^{-8} Torr, diffusion pumped with LN_2 trap) that was used to grow single crystal ZnS on Si.

HITACHI CENTRAL RESEARCH LABORATORIES

Hitachi is another giant that is well-integrated vertically, with an almost unlimited line of products. A third of their output is in semiconductor products, a third in consumer goods (light bulbs, refrigerators, TV, audio, etc.) and a third in industrial products, mostly heavy machinery (motors, generators, nuclear reactors, bulldozers, elevators, etc.) but including computers, communications systems, and scientific and medical instrumentation. Thus, their semiconductor products have a base captive market in their own finished products.

There are about 1000 technical people in the R&D laboratories, working on very diversified programs as expected from the diversity of their products. For example, they are working on TV cameras, for consumer use, now on a Si MOS structure as a possible replacement for their highly successful Saticon (e-beam scanned Se photovoltaic image sensor), LaB₆ electron field emitters, including single crystal emitters, polycrystalline Si solar cells diffraction gratings, 256 kbit bubble memories (GGGarnet), and the 256 kbit Si RAM, which may be commercialized very soon.

Their III-V work is on GaAs MESFET discrete devices and circuits and in optoelectronic devices. If I had visited here first, I would have been more impressed by the sophistication of the work, which is similar to, and competes directly with, work at the other laboratories I visited. Dr. K. Aiki showed me their optical device work. The GaAs DH laser is in production. Work here includes the $0.75 \mu\text{m}$ AlGaAs active layer DH laser for video disc players, and buried active layer InGaAsP/InP emitters for $1.3 \mu\text{m}$ fiber communications systems. Growth is by LPE, halide CVD, and MOCVD.

Their MBE work is concentrated on Si. Dr. Y. Shiraki showed me a new Vacuum Generators three chamber system, which largely replaces an older unit. It handles 2" substrates and it is a true sample transfer (by hooks)--load lock system. The growth chamber is pumped by an oil diffusion pump and it is very well LN_2 trapped. They see no evidence of C contamination coming from it. The growth chamber is LN_2 shrouded with two e-beam hearths at the bottom and four normal effusion cells at an angle. Si substrates are flash cleaned at 1200° , and single crystal Si is grown between 400 and 600° . MOS devices have been fabricated on such material; npnp doping superlattices (300 - 600 \AA) have been made. Growth from amorphous layers has been achieved. Here amorphous Si is deposited below 400° on a single crystal Si substrate. The sample then is heated *in situ* to

about 600. Regrowth starts at the interface and propagates through, finally resulting in the appearance of a streak pattern on the HEED. Aiming at a large area MOSFET thin film transistor technology as the basis for flat panel displays, they have been growing large grain, polycrystalline Si on glass at 500-600°.

Dr. K. Kobayashi showed me some of his results on the structure of the Si/Al interface. From the fine structure of the observed Auger spectra and from XPS (using synchrotron radiation, and done elsewhere), he concludes that the first monolayer of Al deposited on Si strongly covalently bonded, while successive layers are bound much more weakly. There is beautiful science in this.

MITSUBISHI ELECTRIC LSI RESEARCH AND DEVELOPMENT LABORATORIES

The Mitsubishi Electric Corporation, a member of the very diversified Mitsubishi conglomerate, manufacturers everything from stereo equipment, TVs, refrigerators and vacuum cleaners, to motors and elevators, to computers and semiconductor devices. The LSI R&D laboratory in Itami, just outside Osaka, is all I visited. It is not part of the Central Research Laboratory. My host was Dr. H. Miki, Manager of the Research Planning Board.

I spent almost all my time with a group of MBE people: T. Shimano, T. Murotani, S. Mitsui and, the GaAs device member of the group, M. Nakatani. In 1976, they started MBE work on GaAs in a homemade system, but two years later they were forced to drop the work. Now, they are just getting ready to pick it up again. Thus, what I saw was at least three years old. However, that work was well ahead of its time. In a true UHV system, incorporating LEED instead of HEED, and with a real air lock, they were the first to really show the advantages of Si over Sn as an n-type dopant, to make material whose mobility is state of the art today, and to do a thorough surface diffraction study of (100) GaAs as a function of temperature and of As/Ga flux ratio.

I saw an early version of their system, together with a second, later version. The latter was partly dismantled for reconstruction into a much more sophisticated system. The basic system consists of an ion pumped main chamber (10^{-10} Torr) and an ion pumped air lock. The sample is transferred by magnetic manipulation. The sample holder is inserted into a dovetail track and the transfer rod unscrewed magnetically and removed from the main chamber. The air lock contains an Ar ion sputtering gun for cleaning. Inside the main chamber, the sample, heater, and thermocouple assembly is attached to a micromanipulator mount. Six effusion cells surrounded by LN_2 are mounted in a ring about an almost horizontal axis. The As source is a graphite crucible, Ga, Si, and Sn use BN crucibles. (I saw no p-type dopant.) The shutters are manually operated by simple rotary feedthroughs. In addition to the LN_2 surrounding the sources, there is also a small LN_2 shroud behind the sample. Another sputter gun, a quad, and a combination AES/LEED source with screen and cylindrical mirror analyzer complete the growth chamber equipment.

They are now rebuilding the second system, adding a third (analytic) chamber between the growth chamber and the entry chamber in an "L" configuration. Two rods will now be used (at right angles) to transfer the sample in two stages, again using their very positive engage/disengage dovetail track, screw-in rod method. They will use a turbomolecular pump for the entry chamber, an ion pump for the analytic chamber and a cryopump for the growth chamber.

I also saw a brand new Vacuum Generators System in the same laboratory. All I could find out about that, was that it was going to be used for IV-VI materials work.

They told me about their work, now several years old and most of it published. After a H_2O_2 - H_2SO_4 etch, the GaAs (100) substrate is cleaned by Ar ion sputtering, then annealed. This gives better LEED patterns than by annealing only. They grow at $1\mu m/hr$ under an As_4/Ga flux ratio of 6-8. Their undoped material is p-type, $\sim 5 \times 10^{14}$ and low temperature photoluminescence shows the peak normally attributed to C. They went through a detailed LEED study of the growing surface from 400-650°. Between 400 and 450°, the growth is good (morphology, diffraction), but the layers are always very highly resistive, even if $10^{17} Sn$ is incorporated. The mobility is low and the photoluminescence is weak, with indications of deep levels. They assume this is due to native defects. They use such a layer as a high resistance buffer layer beneath their FET active layers. Their original Si doping work, which showed that Si was better than Sn, required that the Si source be outgassed a long time to remove O. Then, they showed that up to a doping level of 10^{18} , the Si was all electrically active and the doping followed the Si vapor pressure curve with temperature rather well. The mobility followed the Rode-Knight curves, with little compensation as deduced from the 77° results. Low temperature, near edge luminescence was strong and sharp, and doping steps less than 350 Å could be made, in contrast with Sn doping. They were able to make MESFETS on $0.3\mu m$ thick Si-doped layers on top of the aforementioned high resistivity buffer layers. With $1\mu m$ long Al gates, they could get 4 W at 8 Ghz. They strongly recommend Mitsubishi-Monsanto S.I. substrates over Sumitomo (less Cr).

I was told about, but did not get a chance to see, work on GaAs MESFET logic and on LPE grown optical devices, some of which are in production or about to be. These included GaAs DH lasers, visible (.78 μm) GaAs active layer LED's and lasers, $1.3\mu m$ InGaAsP/InP lasers and GaAlAs/GaAs concentrator solar cells.

UNIVERSITY VISITS

WASEDA UNIVERSITY

Waseda University is perhaps the most prestigious private university in Japan. Its science and engineering campus is relatively new. It is separated from the main campus, but still in the heart of Tokyo. Research laboratories are small and crowded. Equipment is homemade, or old. Professors are overworked, but student training is good.

Professor Ueda, having just returned the day before from the San Diego crystal growth conference and various visits in the States, showed me around his laboratory. Professor Ueda was one of the pioneers of MBE. His system, homebuilt, is a one chamber (no air lock) ion pumped unit with quad and HEED, crowded in a dark corner of the laboratory. The sample hangs freely from Ta clips in contact with a Pt/Rh thermocouple. Behind it is an unshielded Mo wire spiral heater, also free hanging, to heat the sample. The chamber contains no LN_2 shroud. Although Professor Ueda's early work was on the low gap III-V materials, he is now studying surface chemistry on Si. The Si substrate can be heated to 1300°. From BN effusion cells, he bounces Si and Sb beams off the substrate surface. Via shutters, the quad can look at the incident beam, or at the beam reflected from the surface after an arbitrary delay time. Using pulsed beams, he can measure sticking coefficients and dwell times, much like the GaAs experiments of Arthur and of Foxon and Joyce. For Sb, the primary beam is thermal Sb_4 . The reflected beam, however, shows much conversion to smaller Sb molecules (Sb_3 , Sb_2 , Sb). He is now doing the same with Ga on Si, and he intends to try these experiments also on InSb substrates.

Professor Kimata's original interests were in luminescence and luminescent

materials. He had spent two years working with Garlick, Destriau, and the Curies some 25 years ago. Now he is focused on III-V material preparation by MBE. His system is also homemade, but there is a prepumped entry chamber on top from which the sample is inserted vertically down on a rod. A Cu transfer bellows remains exposed during growth, since the sample is not transferred. The chamber is ion pumped and contains a quad and a homebuilt HEED gun. The sources are vertical with LN₂ enclosed BN effusion cells. The cells (Union Carbide) are made with an indent for insertion of a thermocouple, but these are very fragile and expensive. In a second chamber, they once tried to install almost horizontal cells, but these gave them many problems, so they went back to the vertical arrangement. Their system has LN₂ surrounding the effusion cells but no cryoshrouding behind the substrate. In addition, there is a low energy (~100 eV), low current, ion source in the system. (They also have a separate UHV chamber for UPS work.) They have been growing various III-V materials and alloys (GaSb, InSb, InAs, InGaSb, GaSbAs) on GaAs substrates. These are not lattice matched and the morphology is not good, spots, rather than streak patterns, in HEED. They have studied doping, e.g., S from H₂S in GaSb. They seem to be aiming for Gunn devices. They have also been growing GaN on R-plane and on basal plane sapphire substrates from a Ga beam and NH₃ at 625° (1000 Å/hr) and from Ga, NH₃ and N₂ at 490°. The HEED patterns are spots, never streaks. Their GaN layers are always n-type (10¹⁸-10¹⁹), presumably due to the same native donor defect that dominates GaN crystals grown by other methods. They are going to try *in situ* compensation with Zn. They are also interested in trying AlN.

Professor T. Itoh was my host and guide for my entire Japanese trip. He has been working on the growth and doping of Si by almost every imaginable high vacuum technique. He grows Si and Si-Ge buffer layers by plasma deposition from SiH₄ and GeH₄. He grows on sapphire after first implanting the sapphire with Al, O, or Si. He grows on anodized single crystal substrates. He does ion implantation and pulsed e-beam annealing of implants. Rutherford backscattering is the prime means he uses for assaying the perfection of his crystals. This work is done elsewhere since he does not have a backscattering facility. Most recently, his work has evolved towards true MBE growth of Si, but with a wrinkle. Single crystal Si can be regrown by annealing after ion implantation at temperatures much lower than that needed to grow Si directly from either a Si atomic beam, or from SiH₄. Hence he does MBE of Si from an e-beam heated crucible, but he adds an ionizer and ion extractor to the beam (100-1000eV) so that about 1% of the Si impinging on the substrate is ionized-Si⁺. Good single crystal growth then ensues at low temperatures. In addition, the effective sticking coefficients of neutral Ga and Sb doping beams from separate effusion cells are also increased. Here, presumably the intermixing of these fluxes with the partially ionized Si beam leads to some small ionization of the Ga and Sb. Professor Itoh's goal is cheap solar cell material.

TOKYO INSTITUTE OF TECHNOLOGY

Tokyo Institute of Technology is now housed at two locations. The older campus in Ohokayama (Tokyo) is now reserved for undergraduates, but many research laboratories are still there. The new campus at Nagatsuda, near Yokohama, is about an hour's commute via a suburban rail line from the old campus. It is a very new campus, with modern, spacious buildings, laboratories, and lecture rooms. It is for graduate students only and there are about 500 graduate students there in science and engineering. Professors spend a lot of time commuting back and forth. My host for these visits was Associate Professor H. Ishiwara.

At Ohokayama, I visited Professor Takahashi's laboratories. Unfortunately, Professor Takahashi was away then; but I was guided through by a few of his students. Professor

Takahashi was the pioneer of MBE in Japan. He also originated the use of ionized beams (Zn) for improving the sticking coefficient of dopants. His biggest long-term effort now is in solar cells. He has been working on GaAs/GaAlAs both by LPE and by MBE for concentrator cells. In the LPE work he has been studying the solubility, diffusion, and ionization energy vs. doping of Zn and especially of Be. In the MBE work he is making p AlGaAs/n GaAs graded cells, using Zn as the acceptor. Here, as he has shown, by using a low energy ionized Zn beam, the sticking coefficient of Zn is increased from 10^{-7} to 10^{-2} . This work is being done in a modified version of what is probably the oldest MBE system in Japan. It is a one chamber system with load lock. The entry chamber is diffusion pumped, the main chamber ion pumped to 10^{-9} Torr. The sample stays on the transfer rod, but there is no bellows, the rod is magnetically manipulated. The sources are vertical in a LN_2 can and with magnetically operated shutters. The system is equipped with both a quad and with HEED. I was told that this system is also being used for InGaAs photodiode structures. Be is the acceptor here.

In another simple MBE, with no air lock, and a simple gear with holes in it as the source shutter, nonsingle crystal ZnSe (Mn-doped) was being deposited on GaAs (single or poly) or on ITO on glass for visible displays. The ZnSe is about $0.2 \mu\text{m}$ thick. Al dots are deposited on the surface (MIS or Schottky?). Low voltage (~ 5 V) dc excitation, with the Al negative, leads to high field impact ionization of the Mn and 20-40 ft Lamberts of yellow light. However, as for similar ZnS structures, degradation is a problem.

Professor Takahashi is also working on α -Si for solar cells, but these layers are being grown from a dc glow discharge in SiF_4 and H_2 , not by MBE.

At Ohokayama, I also saw three or four systems for plasma deposition of Si and SiO_2 , an MOCVD reactor (commercial) for GaInAsP (using Et_3Ga and Et_3In in a horizontal reactor), and a JEOL, $0.2 \mu\text{m}$, computer interfaced e-beam lithography unit (in a clean room) used mostly for Josephson junctions and for SAW electrodes.

At the Nagatsuda campus, I met Professor S. Furukawa. His work is on Si. They have their own ion implanter and their own Rutherford backscattering facility. They are doing a lot of laser (Nd-YAG) and cw e-beam annealing and regrowth of implants as well as working with silicides. Associate Professor Ishiwara is working on the latter. He has worked with Pd, Co, Pt and Ni. Ar^+ ion bombardment of evaporated Pd films on Si leads to epitaxial growth of single crystal Pd_2Si even at room temperature. Single crystal Si can then be grown on the silicide. This, I think, is the start of a large government funded push towards three-dimensional LSI. Ishiwara is working on the next step as well, insulators. Evaporation of CaF_2 from a CaF_2 source leads to single crystal growth on Si. However, the growth of Si (plasma growth) on this CaF_2 is only partly single crystal (channeling measurements).

They are also investigating the reversible reaction $\text{SiF}_4 + \text{Si} \rightleftharpoons 2\text{SiF}_2$, which goes to the right at low temperatures and to the left at high temperatures, as a means of growing low cost Si for solar cells. Finally, Dr. Ishiwara described some B analysis he was doing in Si using neutron activation at an (off-site) reactor.

UNIVERSITY OF TSUKUBA

The University of Tsukuba is a brand new university in the new Science City of Tsukuba, close to the Electrotechnical Laboratories, which I will describe later. The university is spread out in modern, spacious buildings. It specializes in science and engineering. They already have a faculty and staff of about 4,000, with close to 10,000

students, 800 at the M.S. level. In modern, cheerful laboratories, they are starting up a good mix of good sciences and engineering research, comparable to a good American university. I met Dr. E. Matsuura, Vice President, and Dr. M. Okazaki, chairman of the Materials Science Department, but I spent most of my time with Dr. Kawabe, who is just starting an MBE project.

Dr. Kawabe has a new Anelva three-chamber system. Although it is a sample transfer system, there is only one magnetically manipulated transfer rod to transfer the sample from the entry chamber into the analytic chamber and to transfer the sample into the growth chamber. The analytic chamber is ion/sublimation pumped, but the growth chamber is diffusion pumped with added LN₂ cryopanelling, so that H₂ can be pumped. It is a 1" substrate system. Eight BN effusion cells are mounted in a LN₂ cooled source flange around a center line 45° from the vertical. There are two openings for 3-beam hearths situated vertically below the sample (only one e-beam hearth is installed). A LN₂ cryoshroud surrounds the sample and the growth chamber also contains HEED and a quad. An Auger system is in the analytic chamber. I saw similar Anelva MBE systems (but with ion or cryopumped growth chambers) at the University of Tokyo, and the Electrotechnical Laboratories.

Dr. Kawabe wants to grow AlGaAs/GaAs superlattices, but he is just getting started. He has already broken Al/Bn crucibles--typical. He controls his Al/Ba ratio by a novel method. He has a vibrating shutter over the Al effusion cell. Using the quad for control, he adjusts the duty cycle of the vibrating (500 m sec) shutter to control the Al beam. This gives him a much more rapid control time constant than he would get by controlling the temperature of the cell.

UNIVERSITY OF TOKYO

The University of Tokyo is the premier university in Japan. I visited, not the main campus, but the Institute of Industrial Science, about five km from the main campus. The work here is science and engineering, but with a practical flavor. In opposition to what I had been told by industry about university research, I found the work here to have an excellent base in pure science; there is good physics and device physics here, much like the best in American universities. The faculty at the Institute teach only graduate courses.

I saw Professor H. Sakaki first. He told me about his calculations of mobility in a modulation doped one-dimensional electron gas structure, his so-called "wire." These calculations predict much higher mobilities than for a two-dimensional confined electron gas. We also discussed his published proposal to build such a structure as a "V" groove structure with a gate controlled field to confine the carriers to the edge of the "V." He has not yet tried to build this structure. He has been studying the Schottky barrier of Al epitaxially grown on GaAs as a function of substrate cleanliness, including intentionally adding O. The barriers are ideal with n (in the I-V expression) equal to one. As the GaAs surface is made cleaner, the barrier height is reduced, implying the existence of negatively charged interface states.

Their work is done on a fairly new three chamber Anelva MBE system, with lots of cryoshrouding and a base pressure of $< 1 \times 10^{-10}$ Torr, a machine almost identical to the one I saw at the University of Tsukuba.

Next I saw Professor T. Ikoma. He is a good theoretician with a good sense of the practical, and he interacts with quite a number of projects, bringing good physics to bear on good experiments. He told me about DLTS and photoexcited DLTS work on GaAs doped

with Fe, e-beam irradiated and then annealed, wherein Fe could be seen first isolated and later paired with native defects. He has worked on the theory of capture into deep levels. He has been involved with acoustic emission from semiconductors induced by mechanical deformation and measured by strain gauges. In GaP LED's, dislocations can be "heard" as they move and "seen" as they lower luminescence efficiency. He has also been working on ZnO varistors and on solid-state electrolytes for WO₃ electrochromics.

TOHOKU UNIVERSITY AND THE SEMICONDUCTOR RESEARCH INSTITUTE

Professor Nishizawa is in a very unique position. He is a professor at Tohoku University, with an associate, two assistants, a technician and about 40 students. He directs most of the research at the university associated Research Institute of Electrical Communication (RIEC). He is the Director of the nonuniversity affiliated, nongovernment supported, Semiconductor Research Institute (SRI) employing 20 scientific staff members. Since I was not able to clearly separate out what Professor Nishizawa does at the University and what he does at SRI, I will discuss them together.

Tohoku University, a government university, is the largest university in the Tohoku (northern) area. It specializes in science and engineering. It has recently moved into a brand new campus on a hill overlooking the city of Sendai. It has large ultra-modern buildings and ample space and facilities. The old campus, close to the center of Sendai (population 600,000) was converted into six research institutes associated with the University. RIEC is one of these. Its predecessor was founded by former Professor Yagi, of Yagi antenna fame. Although the building is old, and not originally designed only for laboratories, they have recently completed construction of a new wing and they are just moving in and spreading out with much up-to-date equipment. Most of Professor Nishizawa's students do their research here, although some use the SRI facilities.

SRI is also unique. Over 20 years ago, Professor Nishizawa patented the p-i-n structure about six months before General Electric (GE) (Bob Hall). This meant that Japanese manufacturers did not have to pay licensing fees to GE. Instead, Nishizawa convinced them to set up the Semiconductor Research Foundation, the industrially supported group that runs SRI. SRI is not affiliated with the University and it receives no government support. It is completely funded by industry, either by specific contracts, by patent royalties, or by direct grants to the Foundation. It has grown slowly over the years. It is situated on the same hills as the new campus.

My reception by Professor Nishizawa in the visitors room at SRI was overwhelming. He speaks rapidly and assuredly, with a twinkle in his eye and a ready chuckle, proud of what he and his colleagues have accomplished and with eager confidence in the future. I saw many working and demonstration models of his devices in bewildering confusion. Too often, I had difficulty in sorting out what was accomplished five years ago, what had just been completed and what was conjectured for the future. However, whenever I interrupted with a question, Professor Nishizawa always answered directly, with no qualification about proprietary material and his answers showed a quick, keen mind with an excellent grasp of the scientific and technological background of his field. I spent the rest of the morning talking to the people and looking at the labs at SRI. In the afternoon, I did likewise at RIEC.

- Static Induction Transistor (SIT)

I am not really aware of the history of the ideas behind the permeable base transistor. However, I do know that Professor Nishizawa envisioned its first cousin, the

Static Induction Transistor (SIT) many years ago along the same lines: current control by altering the voltage-dependent spread of depletion layers between a parallel grid array of reverse biased p-n junctions lying between a source and a drain, and leading to triode-like characteristics, with high input impedance and with both low base (grid) resistance and capacitance. For many years, Professor Nishizawa's group has been fabricating such devices in Si. As Si technology has improved, so have his devices. The characteristics depend primarily on the spacing between the grid lines and on their separation from both the drain and the source. Fine line ($\sim 1 \mu\text{m}$) lithography and concentration depth control by ion implantation have allowed devices to be fabricated in the last ten years that live up to their expectations.

The basic structure of the device is a thin n layer grown on an n⁺ buffer layer (the drain) on an n⁺ substrate. By lithography and implantation, the p⁺ grids (base) are formed. The device goes back into the epitaxial growth reactor in which the rest of the n base is grown, followed by the n⁺ source. The latter may be produced alternatively by implantation. A variation of this is the MOS-SIT in which only the drain and source are formed, no grids. A series of parallel microgrooves are then fabricated exposing the n channel. The valleys are then coated with SiO₂ and a metal so that the depletion layers in the channel can be controlled by the bias on the metal. Another variation is a thyristor-SIT where the drain is replaced by a p⁺ layer. For high power operation the grid of the normal SIT can be forward biased (leading to low input impedance).

The operating devices shown to me include low noise amplifiers, power amplifiers, fast amplifiers, integrated SIT circuits and power thyristors. A small company in the Sendai area is now selling 100-200W SIT power amplifiers for audio use. Mitsubishi and Hitachi are developing the thyristors for power switching. Kw dc switching capabilities have been shown, Mw capabilities are projected. At Mitsubishi Electric VLSI Research Laboratories, which I visited later, I saw both a SIT logic (1 Ghz) frequency synthesizer chip now being commercialized and also discrete power amplifiers (100 W, 1 Ghz; 200 W, 100 Mhz) now being developed. SRI is now working on GaAs SIT as a logic amplifier with an expected Pd product of 0.2 fJ at room temperature. For Si, they can now do close to 1 fJ. I saw devices with delay times in the 20-100ps range, challenging the Josephson junction. (They have an effort in that also.)

- Stoichiometry control during LPE growth of GaP, GaAs and GaAlAs

I saw nine almost identical automatic graphite slider LPE systems, five for GaAs and GaAlAs and four for GaP. The slider is held in a furnace at constant temperature and a vertical thermal gradient across the liquid drives the crystal growth process. Excess GaP source material floats on the surface of the liquid. The well is capped with a cylindrical graphite plug which extends above the slider. On this is wound insulated heater wire to establish the vertical temperature gradient. Thermal equilibrium should now be established in the upper part of the liquid, enough of the GaP source material dissolving to give both the equilibrium concentration of P in the melt and the corresponding pressure above the melt, all corresponding to three-phase equilibrium at the temperature established at the top of the melt. Since the temperature in the lower part of the melt, near the seed is maintained somewhat lower, the solubility of P is less and GaP should precipitate out.

The cap plug has a hole drilled through it. Into it is inserted a quartz tube which leads back to a bulb containing red phosphorus at a cooler, controlled temperature zone in the furnace. Thus, a controlled pressure of P₄ is artificially introduced above the melt. Without this source, the pressure there is automatically set by the three-phase equilibrium pressure corresponding to the temperature near the top of the melt. With this source set

at lower than equilibrium pressure, GaP source material should dissolve and release more P₄ into the gas. At higher than equilibrium pressure, more P₄ dissolves in the melt and more GaP should grow on the substrate. The pressure of P over the melt is not a degree of freedom available for independent control in this three-phase system (the Gibbs phase rule). Near the seed, at a slightly lower temperature, the solution is slightly supersaturated and so GaP crystallizes out, but under conditions close to the three-phase equilibrium near the source. This liquid composition (Ga/P ratio) also predetermines the native defect equilibrium of the crystals grown at that temperature.

They claim that at constant temperature, by altering the P overpressure, they can significantly alter the stoichiometry of the growing crystal, in violation of equilibrium thermodynamics. It seems to me that their results can only be explained by resorting to kinetics. The very small supercooling or supersaturation in the melt close to the growing crystal must translate via a rate limiting step close to or on the growing interface into a large deviation from equilibrium, e.g., a surface stagnant layer through which one of the constituents (Ga or P) diffuses rapidly, the other slowly.

At any rate, a number of different experiments, with P₄ pressure as the parameter, have been performed. All show the same remarkable dependence on pressure: dislocation density, x-ray lattice constant (to five significant figures), near edge photoluminescence efficiency and deep level concentration from photocapacitance. All the curves are cusp-like, with the minimum (maximum for photoluminescence) occurring at the same pressure.

In two sets of very clever thermobalance experiments, in which the P or As pressure is determined where a solid phase just begins to form, they have accurately determined the P-T diagram on the Ga side of the Ga-P and Ga-As phase diagrams for three phase equilibrium. These pressures agree well with the cusp points just mentioned. Thus, they claim that absolute stoichiometry is essential for luminescence efficiency, etc. For GaAs, they note that the site preference of Si also changes at this same equilibrium pressure from an As site at low As pressure to a Ga site at high pressure.

Devices that come from this are:

- GaP green LED's made without N. Here, the lack of nonradiative centers associated with native defects leads to more efficient near gap luminescence, without the N center. This luminescence gives a more saturated green than that due to N. I saw very bright green LED's with an external quantum efficiency of 0.12%.
- Stoichiometry control influences the incorporation of N in N-doped LED's. The solubility of N (from NH₃) in the crystal increases as the P pressure decreases.
- For GaAs DH lasers, little degradation occurs in stoichiometrically prepared material. There are few vacancies, etc., needed for the climb of threading dislocations. Hence darkline defects do not occur.
- I saw very bright GaAlAs single heterostructure red LED's. Here electrons from n GaAl_xAs ($x = 0.7$) are injected and recombine in p GaAl_yAs ($y = 0.3$) emitting at 6650 Å with an external quantum efficiency of 1-3%.

- Their green GaP and red GaAlAs LED's are encapsulated with epoxy lenses, rendering them directional and very bright. They showed me some traffic light mock-ups of arrays of these diodes. They claim that these are now becoming cost-effective in the wake of the rising cost of energy. (2% of Tokyo's electric bill goes for traffic lights.)
- I saw a series of beautiful surface micrographs of LPE grown epilayers, showing spiral ramps singly and in pairs (Frank-Read screw dislocation growth mechanism).
- Tunnett (tunnel injection-transit time limited)

This is an Impatt type device, where the very high field at a reverse biased tunnel diode produces pairs very rapidly and injects them into a thin drift region. The structure in GaAs is grown by LPE. A $0.4 \mu m$ v drift region is grown on an n^+ buffer layer. Then comes the very thin (1000 \AA) 10^{18} (sulfur) doped tunneling layer. This is followed by a p^+ (Ge) cap. They observe (pulsed) free oscillations at 300 Ghz! They are now working toward cw operation at 300 Ghz and pulsed operation at 1 Thz. This means trying to make the n^+ layer thinner.

- Si floating-zone - Low dislocation Si, $<1/\text{cm}^2$, is grown in high vacuum, by fast pulling (3 mm/min) in a $\bar{1}\bar{1}\bar{1}$ direction. $1\frac{1}{2}''$ dia. ingots are produced.
- Heavy doping of Si with B shrinks the lattice, inducing dislocations. Simultaneously doping with a counteracting large Group IV element, Sn, relieves the strain and reduces the dislocations generated.
- Infrared absorption through the gas stream close to the growing surface of Si in a $\text{SiCl}_x\text{H}_{4-x}$ reactor shows that SiCl_2 is the final reactive molecule in the gas phase.
- I saw a brand new Si MBE system that was not yet operational. It is UHV (10^{-10} Torr) with a cryoshroud designed for LHe. It is equipped with HEED and e-beam heated sources and will be used for the growth of silicides on Si.
- SAW devices - AlN is grown on Si or sapphire by MOCVD (with NH_3) at 1200° in a vertical, RF heated reactor with rotating substrate and input gases mixed right over the substrate to prevent premature reaction. On Si, the AlN is not single crystal, but it is oriented with respect to the c axis. ZnO is also grown by MO ($\text{ZnEt}_2 + \text{O}_2$) on Si. Again, the c-axis is oriented.
- GaN_xO_y passivated GaAs - GaN is grown from GaBr and NH_3 at $400-600^\circ$ on GaAs. It is microcrystalline, with low resistivity and with poor adhesion. Mixing O_2 with the NH_3 yields a GaN_xO_y film (O/N determined by sputtered Auger analysis) which has better adhesion, high resistivity, and few interfacial states ($10^{11}/\text{cm}^2$). A SiO_2 capping layer improves environmental stability.
- Photoacoustic observation of nonradiative recombination - A GaP wafer is placed on a piezoelectric transducer. The surface is scanned with a sharply focused greater than bandgap light source. The electron-hole pairs so produced yield radiative recombination mostly. When the exciting beam strikes a region of the crystal near dislocations a pulse of thermal energy is left behind as the beam scans by. The sudden heat pulse produces an elastic acoustic wave which is detected by the transducer. The two-dimensional map thus produced correlates well with dislocations and dark spots in the luminescence pattern.

- Semiconductor Raman laser - LO and TO emission from GaP pumped with a Q-switched Nd/YAG laser can be stimulated. Polishing the GaP, adding antireflection coatings and placing it in an external Fabry Perot cavity with strong pumping leads to lasing on those transitions.
- Blue emitting ZnSe LED's - They told me that they had obtained true p-n junctions in ZnSe! I was never shown these diodes and in the press of so many other things to see, I forgot to follow this up.
- Josephson junctions - There is a large effort here, but I did not see any of it.
- Equipment - Some of the equipment is old, some new; much of it was built here. I saw five x-ray instruments including a double crystal spectrometer and a very high intensity machine. I also saw an epr system and a 2 MeV Rutherford backscattering system.

OSAKA UNIVERSITY

My time here was spent completely in the laboratories of Professor S. Namba. Professor Namba heads both the Solid State Electronics Laboratory and the Microfabrication Laboratory here, and he is also the director of the semiconductor group at RIKEN. I will describe the activities at RIKEN later. At Osaka, his group includes two associate professors, three research assistants, three technical assistants, four Ph.D. students and eight M.S. students. Because Professor Namba was away, my host and guide was Associate Professor K. Gamo.

There is a variety of work in this group, mostly centered on microfabrication and ion implantation. Spectroscopy and quantum electronics work is done at RIKEN and will be described later. The Ministry of Education is strongly supporting an effort in microfabriation down to 100 Å resolution, and will soon expand this to 10 Å. That is the focus of most of the work I was shown:

- They have a JEOL computer controlled system for direct e-beam writing on PMMA.
- They are doing x-ray lithography on PMMA, using an electron synchrotron source at the University of Tokyo. They use masks of Au on either mylar, perylene, thinned Si, or thinned Si coated with Si_3N_4 . I saw photographs of $0.5 \mu\text{m}$ wide channels cut in PMMA with smooth, vertical walls.
- Ion beam lithography, using protons, on PMMA through Au/thin Si masks gives them $<0.1 \mu\text{m}$ resolution.
- They do direct ion implantation writing on Si wafers, using wetted field emitter point sources for ion generation. For high melting point implants they use low melting point eutectics for the source. For B, they use a B/Pt eutectic; for Si they use a Si/Au eutectic. After emission, an E x B mass selector separates the B (Si) ions from the Pt (Au). A 60 keV 1 nA beam is focussed down to 1,000 Å.
- Reactive ion etching with CF_4 is used to etch SiO_2 through PMMA masks. Much work went into finding the optimum conditions to do this. They can make optical gratings of SiO_2 on Si this way and can even build in a blaze angle by tilting the substrate with respect to the etching ion beam.

- Laser holography is being used to fabricate distributed feedback reflectors on InGaAsP for integrated optics.

There is also a large effort on laser annealing of implanted Si and GaAs using CW (Ar,CO₂) and pulsed (Q-switched ruby) sources. Rutherford backscattering, DLTS, photocapacitance, and photoluminescence are used to characterize the results. They are growing α -Si which exhibits few gap states and which evolves little H₂ on heating. Microfabrication techniques are being used to build microbridges and point contacts of Nb to Nb on Si substrates for Josephson junctions.

I wanted to see Professor Hamakawa and his work on α -Si solar cells and on InGaAsP light emitters, but he was not there. I did see his old MBE system, built for him by Anelva. It is a one chamber system with an air lock. The sample stays on the rod which is manipulated through a bellows. There are six effusion cells with pneumatic shutters. There was no HEED or Auger visible I was told that Professor Hamakawa has a new system on order.

KYOTO UNIVERSITY

Here I visited the Department of Electronic Engineering, and in particular, the laboratories of Professors Matsunami and Takagi.

Associate Professor H. Matsunami runs the Semiconductor Engineering Laboratory together with three research associates. His previous work has been on PLAT and on LPE grown SiC, from which he has fabricated blue LED's. The SiC work is continuing, now using DVD growth techniques and he is working on AnSe and InGaAsP, both for visible light emitters and lasers, on MIS solar cells (metal/poly Si/Si) and on α -Si and α -SiC, using EBIC and DLTS extensively to characterize the latter.

In their now abandoned LPE growth of SiC, a dip rod containing a SiC seed was inserted into molten Si at ~1600 contained in a graphite crucible. The dip rod kept the seed slightly cooler than the melt. C from the crucible dissolved in the melt and SiC grew on the seed in this thermal gradient LPE technique. Now the SiC is grown by CVD from SiCl₄ and propane in 1 atm of H₂ at 1200°. The seed is placed on a graphite susceptor in a horizontal, water cooled, quartz reactor and heated by an external RF source; p-type *in situ* doping is by Al, Ga (metalorganic sources) and B, n-type *in situ* doping is by N, P and As (hydride sources). The SiC grows single crystal on a SiC substrate, but not on a Si substrate, presumably because of the poor lattice match. By analogy with the growth of single crystal Si on sapphire, also a lattice mismatched system, in which a thin imperfect buffer layer first forms at the interface and on which good single crystal Si grows, they tried the same approach here. A 1000 Å layer of SiC is first sputtered onto the Si substrate. On this, CVD growth results in single crystal SiC deposited epitaxially with respect to the underlying Si substrate. At 1200°, the SiC is always cubic (3C, β SiC), whereas at the higher LPE growth temperatures (~1600°) a mixture of hexagonal and various polytypes resulted.

Following Choyke and Patrick, they have done low temperature (LHe), high resolution photoluminescence, following the free exciton, the various bound excitons, and the discrete donor-acceptor pair lines as a function of polytype. From these results, they deduce the site (Si,C) occupied by the various donors and acceptors. In the polytypes there are more than one distinct Si or C site. From the Haynes' Rule, the donor and acceptor binding energies are traced through the various polytypes.

In SiC, all the "shallow" acceptor levels deduced are relatively deep (~0.2 eV), so that very high doping levels are required to obtain low resistivity p-type material at room temperature. They have made LED's from p-n junctions prepared during growth. They view an MOS structure they have fabricated as a first step towards a high temperature SiC transistor technology. They want to build controlled heterostructures between polytypes (1200° CVD growth atop 1600° LPE substrates). One of Dr. Matsunami's associates is now at NASA/Langley continuing some of the SiC work there.

Professor T. Takagi is another man who runs a small empire. He holds the Chair of Electron Devices in the Department of Electronic Engineering and he heads the Ion Beam Engineering Experimental Laboratory, a brand new three story modern laboratory building, housing many large machines. He has two associate professors, two research associates, a technical assistant, two Ph.D students, eight M.S. students and six B.S. students working with him. Here again is a man, like Professor Nishizawa of Tohoku University, who has started a major new line of technology with a minimal basis in science. He also commands a very substantial research effort. Professor Takagi started in industry working on microwave vacuum tubes (Klystrons, magnetrons), then came to Kyoto University where he broadened his base from e-beams to ion beams. His big contribution is the "ionized cluster beam" technique, by which he can grow layers of almost any metal, semiconductor, or insulator.

The physical mechanisms underlying this method of growth are relatively exotic, and a lot more work would be required to understand the physical and chemical bases for this technique. The method starts with a heated Knudsen cell containing a source material which generates a vapor pressure typically of 10^{-2} Torr, but up to several Torr has been used. The Knudsen cell port (~1 mm) is much larger than the mean free path inside. The gas effuses out into a vacuum of only 10^{-6} Torr (not UHV). On leaving the port, the gas undergoes rapid adiabatic expansion, cooling the gas significantly, so that the atoms now have very low kinetic energies.

The first significant point is that as these atoms approach each other, their energies are too small to overcome activation energies for the formation of true chemical bonds, but they are attracted to each other and can become attached weak Van der Waals forces forming weakly bonded clusters. Using simple nucleation theory (but with poorly defined bulk and surface energies), there must be a critical radius, (minimum number of atoms) below which a cluster should not be stable. From ionized cluster-Faraday cup measurements, this is determined to be 500-2,000 atoms.

The second significant step is that the beam of neutral clusters (mostly confined to $\pm 15^\circ$ of the normal to the port) is now ionized by being sprayed with electrons from an electron gun (200-1000 V, acceleration). Only one atom in any cluster can be ionized, because Coulombic repulsion would dissociate the cluster if more than one atom became ionized. Ten to 50% of the clusters are now ionized. The ionized clusters are now accelerated electrostatically with an accelerating voltage of 0-10 kV. The clusters then impinge on the substrate giving growth rates of 500 Å to several μm per minute. The accelerating voltage must be chosen high enough for good growth, but low enough to avoid resputtering of the growing material.

Charged, accelerated clusters are far more effective in inducing single crystal epitaxial growth than are neutral clusters. For neutral clusters, high substrate temperatures are needed for the high surface diffusivity necessary for good single crystal growth. With ionized clusters, good single crystals can be grown at much lower substrate temperatures. Each cluster has only a single charge and it is accelerated to about 1000 V,

so that the energy available per atom in the ~1,000 atom cluster is 1 eV or less. This may provide the surface diffusion activation energy normally supplied by thermal means--the heated substrate. However, Dr. Takagi believes that it is the charge itself, rather than the energy, that is crucial. He cites the observation that good crystal growth can be obtained when only a small fraction, ~1%, of the clusters are ionized, so that the average energy per cluster an per atom in the cluster, is very low. Somehow, the charge does something to the surface which speeds up surface diffusion.

With this technique, all sorts of metals and semiconductors (Cu, Si, Au, Pb, InSb) are grown as epitaxial single crystals on appropriately chosen substrates.

Reactive ionized cluster beam deposition is an extension of this method in which a reactive gas ($\sim 10^{-4}$ Torr) is admitted to the vacuum chamber. With acetylene and a Ti cluster beam, TiC is grown. With O_2 and a Be beam, BeO is grown. On a Si substrate, the latter is oriented but not single crystal and its resistivity at room temperature is $10^{13} \Omega \text{cm}$. ZnS is grown from a single source beam. Simultaneous doping with a Mn^+ ion beam produces large area ZnS:Mn dc EL panels. The substrate must be held at 400° to activate the Mn to obtain the 5850 \AA Mn emission, but no co-activator is needed. Multilayer low resistivity ohmic contacts to Si and other semiconductors can be grown at room temperature, with no subsequent annealing steps necessary.

Single crystals, polycrystalline, and amorphous material have been deposited on metals, glass, plastics, etc. They have grown Au, Cu, Ag, Pb, Si, GaAs, GaP, ZnS, CdTe, MnBi, ZnO, BeO, PbO, SnO₂, GaN, InSb and some garnets. MnBi for magnetooptic devices grows oriented on glass. ZnO for SAW devices grows oriented on sapphire or on glass. BeO for use as a thermal conductor or electrical insulator grows oriented on sapphire.

I saw many machines, from small UHV systems with sophisticated surface analytic tools on board (basically MBE machines with added facilities for beam ionization) to very large systems with multiported Knudsen cells designed for continuous coating of one meter wide rolls of metal or plastic. In addition, there was work on ion source development, ion implantation and ion plating. I had no time left to see these.

INSTITUTE VISITS

INSTITUTE OF PHYSICAL AND CHEMICAL RESEARCH - RIKEN

RIKEN is a large government run science center in Saitama, just outside Tokyo. Its goals are in pure science, although much of the science is in areas which can be easily commercialized. Fifteen percent of their budget comes from industry, the remainder, directly from the government for a total annual budget of \$40 million. It is a "showy" institute with large cyclotrons, linear accelerators, and powerful lasers. Six hundred people work here including 212 Ph.D.s. Only 20% of the staff are in clerical and administrative positions. As in industry and in the universities, there are very few technicians; the bench scientist does all the work, frequently even in the machine shop. There is a lot of ultramodern equipment here mixed with a lot of ancient equipment; but it all seems to work well together, e.g., a modern microprocessor controlling an old vacuum tube power supply. The institute is run by Fellows, mostly university professors. The chief of the Semiconductor Laboratory is Professor Namba whose laboratories I visited at Osaka University. He was not in Osaka when I visited there and he was not at RIKEN when I visited here. He normally spends one or two days a week at RIKEN.

Dr. Pil Hyon Kim was my host and guide. We looked at the semiconductor growth first. PbSnTe is being grown on PbTe by LPE using a rotating slider. CdZnS alloys are being grown by sublimation in H₂S. There is also an MBE system here, but it was being moved and I could not see it.

Much of the crystal growth feeds the laser group which works, first, on understanding optical interactions in solids, and second, on the development of new lasers. They have (at least) two systems for amplifying and generating second and third harmonic signals from a pulsed Nd-YAG laser. One uses the third harmonic to pump a dye laser (25 pc). Another acts as a source for external experiments involving the three coherent beams, the fundamental and the first two harmonics. In one such experiment, the second harmonic is split and recombined on a CdS surface. The resultant grating image generates free excitons in the crystal, forming an exciton grating just below the surface. The third harmonic is used as a probe of the grating, diffraction vs time enabling exciton diffusion to be followed. Free exciton polariton effects and their time evolution in CdS and in CuCl have been studied with this system and with a N₂ laser pumped dye laser. I saw an array of modern lasers and associated equipment. They have a high power CO₂ TEA laser, and a commercial excimer laser and they are designing a new monster excimer laser. They have an e-beam pumped (77°K) II-VI semiconductor laser system. Finally, I saw an excimer laser being used to induce the reaction of Ba and I₂ molecular beams at low pressures to form BaI₂.

In the Friction and Lubrication Laboratory, Dr. M. Iwaki showed me a number of practically oriented experiments designed to reduce corrosion and friction of metals. In a homemade ion implantation system, Cr was implanted into iron and steel. Toyota now uses this process commercially to make a cheap, corrosion resistant steel. They are also doing ion plating, e.g., Si on Al and Mg.

The "showy" part of RIKEN, mostly for various high energy physics experiments, includes a tandem accelerator, a cyclotron, a new cyclotron now being built, expected completion date, 1990, and an almost operational 4 MeV variable frequency linear accelerator, eventually to feed the new cyclotron. In all of these, the emphasis is on high energy ion beams of heavy elements. Their connection with semiconductor work comes from ports for channeling and backscattering experiments at high energies and with heavy ions, and a study of x-ray and auger electron emission during ion implantation.

ELECTROTECHNICAL LABORATORY (ETL)

MITI operates several institutes in the new Science City of Tsukuba, near the University of Tsukuba and about 1½ hours north of Tokyo. ETL is one of them. It moved here only about two years ago from a site much closer to Tokyo. There are about 600 professionals here working on the general projects of national interest that MITI supports. The types of project MITI is pushing are mostly energy related, but they include electronics and optoelectronics, space, nuclear energy, bionics, manufacturing systems and medical instrumentation.

ETL is truly the home of MBE in Japan. I counted at least 13 systems here. Ten of these are under Dr. S. Gonda, Head of the Electronic Refactory Materials Section of the Materials Division, my host at ETL. The emphasis here is on materials preparation of refractory materials. Although they also work on Si and GaAs, their biggest push is on SiC and on the III-V phosphides (GaP, InP) and nitrides (AlN, GaN). Their immediate goal is not the physics of the material, nor devices. It is strongly focused on the preparation and

characterization of these difficult materials. Here again, as I had come to expect, it was one man per machine, with no technician, but the individual researchers work closely together. Also, each machine is used for only one material.

It is difficult for them to get large amounts of money at one time, so that many of the systems I saw were put together over a period of years, sometimes using components from older systems. Of the ten units in Dr. Gonda's group, two are standard commercial machines - a Varian 360 and a standard Anelva machine. The rest was either put together for them by Ulvac or Anelva or were assembled here. A history of MBE in Japan could probably be compiled by looking at all these systems. The evolution of MBE, from almost simple evaporators to the most modern sophisticated systems, is here to behold. I saw too many machines to describe any in detail, but most are first-class systems. Not all the units have all the frills. At least two have no air locks. Few have Auger analysis. Some are diffusion pumped (but with massive LN₂ cryopanels). Some have little or no cryoshielding surrounding the sample. Some have ESCA, and many have ion beam sources and e-beam hearths. HEED here is done with electron energies up to 50 keV. For many of these refractory materials, very high substrate temperature are needed. These are obtained either by direct resistive heating or by radiation heating from a spiral Mo heater. An optical pyrometer measures the temperature.

GaAs and GaAlAs are being grown in the Varian 360 system for quantum well structures. Polycrystalline InP is being grown on glass for photovoltaic possibilities. I wondered why this was being done by MBE. The system here is an Ulvac 1" substrate system, one growth chamber with air lock and sample transfer, four source cells and a LN₂ cryoshroud. The phosphorus source is red phosphorus. I was told that this machine was a prototype for a standard MBE line by Ulvac. There are two machines growing GaP (both using red phosphorus). One has no air lock. The system is baked out after every run, the phosphorus being pumped into a sorption pump. The GaP is being grown both on GaP and on Si. Previously they could not get planar growth on (111) Si, but now they use (100) Si and the growth is planar. They do not use (110) Si or the more exotic nonpolar surfaces investigated by Kroemer of University of California, Santa Barbara. I do not know how they avoid antiphase boundaries. I think they are more interested in growing thick GaP layers, rather than in focusing on what happens close to the interface. They clean the Si by flash heating to 1200°. The Si is heated resistively. Growth occurs at only 400°, and doping is by Sn(n) or by a low energy ion beam for Zn(p). 300 Å npnp doping superlattices were being made by growing Si on Si. The Si is from an e-beam evaporation source. The dopants, Ga and Sb, come from low energy ion sources. AlN is being grown for use in SAW and EL devices on sapphire and on Si. The Al source is from an e-beam hearth, the N from an NH₃ leak. The system is oil diffusion pumped through a LN₂ trap. Growth is at 1100°. They are setting up two new machines, one for AlGaN and one for GaN. There are two machines for growing Sic. Both use Si beams from an e-beam heated hearth. Finding a good source for C is another matter. They started with e-beam heating of graphite, then CH₄, then they cracked the CH₄ and finally, they ionized it. Their second machine is basically a large ion source machine with a small growth chamber tacked on at one end. CO₂ is the source gas (O₂ is easier to pump than H₂). After ionization, the C is separated by an E x B mass selector, neutrals are removed, and the ions are accelerated to up to 1000 eV. This large unit gives an ion current of 100 μa. This is still not enough. They grow mostly on sapphire. They would like to make heterojunctions and superlattices between the various SiC polytypes, if they can learn to grow them reproducibly. They are also growing Nb₃Ge for Josephson junctions, using the native oxide, Nb₂O₅, grown *in situ*, as the insulator. I saw two MBE systems, each built around an HP ESCA machine to facilitate studying and controlling the oxide. I saw several other MBE systems, but I do not know if

they were being used currently. I was also told about two other machines being used to grow ZnSe. They apparently have given up on trying to make p-type ZnSe and they are building MIS structures for large area flat panel displays using the high field impact ionization of luminescence centers mechanisms for the EL.

PART B: COMMENTS AND OBSERVATIONS ON JAPAN AND JAPANESE SCIENCE

During my tour of Japanese laboratories, I consciously attempted to learn something about Japanese approach to science and technology that appears so different from ours. I have never understood how science and engineering are done in Japan. Ten or twenty years ago this would have been just another thing I would never come to understand. However, today, with Japanese technology all around me, with Japan Incorporated ahead of us or just at our heels in so many areas of electronics and communications, it becomes much more important to understand their way of doing things, partly to try to predict the future (where will they be ten years from now?), partly to alter the way we do things (do they do things better?).

I have met and worked with individual Japanese scientists in this country. They became my friends; but I learned little from them as individuals, as to what really makes the Japanese way of doing things so unique (unique to us). And there in, I think lies the answer. As individuals they are not unique. As a group, however, they are awesome.

I have usually been troubled reading Japanese papers, and listening to their oral presentations. Aside, from the inevitable language problems, I find the papers boring, going over much old material, but not placing any emphasis on the new material. In fact, their papers are to me completely flat, with no emphasis at all, even on new things, even on highly unusual results, even on major breakthroughs or flagrant violations of fundamental principles. They never start a paper with, "For the first time we show that..." Their papers feel like detailed solutions to old textbook problems, with, perhaps, new results, but no advances in fundamentals. The only hint that something unusual is happening is the (often) large number of coauthors.

The week before my trip to Japan, I attended a joint American Association of Crystal Growth-International Vapor Phase Epitaxy Conference in San Diego. There were a series of papers in one MBE session on the preparation and properties of the two-dimensional electron gas in undoped GaAs confined close to its interface with an n-type doped GaAlAs layer. Here the carriers originally come from the doped layer, but in the GaAs where they wind up, there are no ionized impurities to degrade their mobility. Thus, very high electron mobilities become possible, especially at low temperatures, an effect first demonstrated at Bell Laboratories, less than two years ago and called modulation doping. At the Conference there were several papers describing the MBE growth of such selectively doped layers. All ended with a measured high electron mobility at 77°K. The last paper was Japanese (Hiyamizu, et al. of Fujitsu Laboratories). He described the growth and the high mobility at 77°(and also down to liquid He). Then he added a slide showing the fabrication of an FET where the channel was the two-dimensional gas. He mentioned measurements on ring oscillators of both depletion mode and enhancement mode devices. (I actually saw these several weeks later.) Delay times of 56 ps and 17 ps were measured at 300 and 77°K, respectively. Two things stand out about this ending. First, the observation of a high mobility is not a valid goal or ending. Second, he did not mention that the gauntlet has been thrown down to Josephson junctions. This device, called the High Electron Mobility Transistor or HEMT in Japan.

Another example of problems that troubled me was a group of several papers in the last three years by Professor Nishizawa of Tohoku University. He reports phenomenal properties of GaP and GaAs LED's, lasers, and other devices made by a very special processing technique. The technique described apparently violates some well-established thermodynamic principles, namely the Gibbs Phase Rule. On that basis, I never would have done the experiment in the first place. Yet Professor Nishizawa did, with the aforementioned fabulous results. He knows that there appears to be a violation of fundamental principles. (I spent a day with him and saw these devices. They are every bit as good as he claims.) I could never present a paper whose results appear to be a contradiction of thermodynamics. I would go back to look for the "correct" explanation. Not so Professor Nishizawa. To him, the device is the explanation. (By the way, Professor Nishizawa is a wonderful person, eager to explain and answer questions and a good host.)

Clearly Japanese science and engineering is very different from the way it is practiced here. Why? Is this why stereos, VCR's, etc., are mostly made in Japan? What does this bode for the future? Are we doing something wrong?

My trip was set up as a greatly expanded version of the MBE-Japan tour that Professor H. Kroemer took the summer before. I am very grateful to Professor T. Itoh of Waseda University who did the scheduling, arranged the visits and accompanied me on most of the trips. (Former students give him contacts at many industrial and government labs.) Professor Itoh was able to open many doors for me, in part because I came with the title of professor, a very respected and prestigious title in Japan, (but not one that commands high monetary rewards there).

I spent four weeks in Japan in August 1981. This is the worst time to visit. Industrial laboratories close for vacation for two weeks. It is the Obon holiday season. Trains and planes are booked far in advance. At universities, professors are usually away, often abroad. And the weather is at its worst, hot and humid, like Washington, D.C. in the summer.

I visited seven industrial R&D laboratories. (NTT-Musashino, Fujitsu Laboratories, Toshiba R&D Center, Sony Research Center, NEC, Hitachi Central Research Laboratories, and Mitsubishi Electric), seven universities (Waseda University, Tokyo Institute of Technology Ohokayama and Nagatsuda, University of Tsukuba, University of Tokyo, Tohoku University, Osaka University, and Kyoto University), two government laboratories (Institute of Physical and Chemical Research-RIKEN, and the Electrotechnical Laboratory - ETL) and one independent institute (Semiconductor Research Institute). These are mostly elite institutions, but they are typical in the sense that the good semiconductor work comes from such institutions.

I was very well-treated at all these places, almost royally. Conversation was free and easy with no evidence of confidential material being withheld (although none of my visits was to a production facility). I met old friends, made new friends, learned much and enjoyed the experience greatly. Yet, I left Japan with purchases of an almost all electronic camera, a Sony Walkman, a digital calculator watch, a pearl necklace and earrings and some traditional Japanese clay figures. This assortment from the old and new Japan represents what Japan is today! These are my own observations and misinterpretations of what I saw or was told. I realize that generalizations can be so tainted with exceptions, that they can become useless; but in Japan with its very homogeneous society, and small statistical spread, pat generalizations can be apropos.

THE PEOPLE

The most significant attribute of the Japanese people is its homogeneity. This slowly dawns on a visitor, as he realizes that Japan was a feudal agricultural society 100 years ago. The Meiji period saw the penetration of Western products and culture, but only as an overlay to what was already well-entrenched, and never by immigration. Thus, there are no minorities, outside the mainstream. In a very mountainous country the size of California, with a population half that of the U.S. and with no significant natural resources, the paramount resource of Japan is its people, and the homogeneity allows easy utilization of this resource.

There is no room in such a crowded country for individualism. Everyone must conform to strictly dictated societal rules. The Japanese spoken language sounds rather flat, no intonations or accents, and the accepted methods of thinking and feeling must parallel that. Western logical thinking, going back to Plato, and serving as the basis for Western science, is based on a logical stream of strong, positive statements. Dr. Makoto Kikuchi, the director of the Sony Research Center, who has lived and traveled extensively around the world, and who I have known for 20 years, wrote an article for the September 1981 issue of *Physics Today* in which he tries to explain the unique method of Japanese thinking in terms of pattern recognition and association rather than the linear logic we use. Thus, there are no strong assertions to be made. "Yes" and "No" are modified with "maybe." I am told that Americans learning Japanese are perplexed by the fact that whenever a Japanese ends a sentence he adds a word or phrase meaning "perhaps" or more or less." Thus, it takes many more words to make oneself absolutely clear to a Westerner. But, to a Japanese in his tightly homogeneous society, the meaning is clear at once. He, too, thinks that way. Kikuchi's article itself is a beautiful example of this. It is not a linear essay of logical deductions, step by step. Rather it is a series of loosely connected stories, parables and metaphors, a lot like later portions of the Bible. Yet his meaning eventually becomes clear (more or less).

This common mode of gestalt thinking has great advantages. Everyone understands everyone else easily and decisions are easy to arrive at by common consensus. Thus, given the same inputs, every person will arrive at the same conclusions. So management does not have the decision-making burden that managers do here. All the people who would be affected by the decision can take part in making the decision--consensus. Thus, everyone feels he is responsible for his own destiny as well as that of the other around him.

This mode of thinking has its disadvantages. Individuality, innovation, initiative are filtered out and not permitted. This is the toughest problem Japanese science and engineering face now according to most scientists and managers I spoke to. Catching up to the U.S. in electronics was easy. The novel ideas were imported. The singlemindedness of the Japanese mind could copy easily. The obvious next steps were also easy to project with clear-cut goals of commercialized devices: smaller, more reliable, fewer defects. But now, where do the next major breakthroughs come from? Everyone I spoke to believed that Japan was good at technology and implementation, but only the U.S. could achieve basic scientific innovation. This is an example of consensus thinking at its highest.

From the tradition of Westernization that began 100 years ago, one gets the feeling that everyone believes that anything Western (culture, science, art) must be good. But these are assumed only with a strict Japanese overlay. Thus, teen-age disco-dancers I saw were all similarly attired and doing the identical dance steps. Little individualism comes through. Similarly, given a new scientific innovation, I think that the response would be uniform and predictable in this monolithic society. This uniformity is further strengthened by the Japanese educational system as discussed below.

As Japan moved from an agricultural society to an industrial one, the cities grew. People constantly talk about their hometowns. The extended family broke up, but the nuclear family is still the basis of society. I think the role of the extended family is now played by the company for which a person works. More on this later. The unemployment rate is infinitesimal. Salary ranges are much narrower than in the U.S. Young women, just out of high school will work for about 10 years before getting married. At this point, without responsibilities they are relatively rich and fill the many restaurants in the cities. They then marry (usually arranged) and settle down to raise a family. I saw no women working as full-fledged scientists or as graduate students. It is not done.

Although the standard of living is still below that of the U.S., it is fast catching up. The Japanese people work hard, five long days and Saturday mornings. Leisure is restricted. The cities are crowded. Large American style houses on large lots do not exist. To feel that you have made it, you buy consumer products: cameras, stereos, VCR's, etc. Thus Japan itself is the base market for all the large Japanese electronics companies. Because Japanese all have a high level of education, product selection is based upon a great deal of knowledge and sophistication. Thus, if a product makes it in this market it will make it in the export market. I think that the acquisition of consumer products to a Japanese, living in a small house in a crowded city, is more an expression of individualism than that of conspicuous consumption.

THE UNIVERSITIES

Japan is a country about the size of California. It is mountainous with few natural resources, but its population is roughly half that of the U.S. Its key natural resource is its people, and its prime export is high technology. Electronics, the kingpin of high technology, has become so successful because the people achieve a high level of education, and because the people work well together in groups with common goals, the latter following from the homogeneous, monolithic nature of the society. A desire for education and a willingness to work hard are fundamental characteristics of the Japanese people today.

Japanese universities currently turn out about three times as many electronics graduates on a per capita basis as does the U.S., 1½ times on an absolute basis. These are the cream of the crop of their students. On the average, their training has been more rigorous and more comprehensive than that received at most American universities.

The electronics industry is now perceived as the employer of greatest prestige. Thus, it gets the best students. The dozen or so largest electronics companies, combining prestige and life-long security, become student targets at a very early stage of the students education. To get there, you need an M.S. degree from a prestigious school and you must pass the company's entrance exam. To get into a prestigious university requires that you pass the university entrance exam. Coming from a prestigious secondary school helps. Therefore parents start pushing their children very early. To get on the right track, you must start with the right kindergarten! A student's immediate goal in life then becomes to pass the next entrance exam. He may spend an extra two hours a day after his normal school period, attending classes to assist him specifically in preparing for that next exam. Thus, he is being trained to answer the kinds of questions asked: to memorize, to think analytically. Little premium is placed on inductive thinking, on being creative or innovative. This part of his education, stressing individuality, is neglected.

The curriculum in all the primary and secondary schools is controlled tightly by the Ministry of Education. The students are all trained identically, again discouraging individualism, but the quality and the quantity of education are very high.

The few old imperial universities were reorganized after the war into a European style system and more schools were founded. These are the public, state-run universities. Each department, typically, has several (full) professors. Under each professor is one associate (professor) and two or three assistants. Assistants do not have tenure. Normally, it takes 15 years to get a promotion and acquire tenure. They are utilized by the professor, very much as permanent postdoctorals.

Research is done primarily by M.S. students. (The M.S. is the desired degree for entry into the electronics industry.) A professor might have, at any one time, one Ph.D. student, five M.S. students and three B.S. students working in his laboratories. The M.S. research goal usually is one or two papers, often done jointly with other students. Students work closely together and an assistant is usually strongly involved. The assistants and the associate may be working on similar projects. Two full professors in the same department may be working in the same field. Here I sensed little or no cooperation.

Without another entrance exam, the professor selects a good M.S. student for a Ph.D. thesis. No more courses are taken, just three-five years more of working on a thesis with long-range goals. This student now works directly with the professor and they develop a very close relationship, the student taking on many of the professor's administrative and secretarial tasks. This Ph.D. degree is the entrance to academia. When the student finishes, the professor will place him as an assistant in his own laboratory (or at another university, the latter made possible by the ever-expanding university structure in Japan). This results in inbreeding, again discouraging individualism and individual creativity.

The typical ongoing teaching load for a professor is one graduate course and one undergraduate course, each entailing one 1½ hour lecture and one 1½ discussion section or seminar per week. In Electrical Engineering (really Electronics and Communications Engineering departments), there are many very specialized courses even at the B.S. level, courses in semiconductor processing, crystal growth, microfabrication, devices, etc. Even outside majors: chemists, etc., knowing the directions in industry, take such courses. In principle then, a finishing M.S. student is ready to assume a position in industry with very little additional on the job training.

American schools start electrical engineers specializing only at the graduate level, e.g., into the broad field of electronics. More specific specialization occurs primarily only at the Ph.D. level. In Japan, students enter the universities with a more advanced secondary school background, and the students seem to know what they want (often a problem in our country), so that specialization can start early. Thus, as far as specialty courses are concerned, their B.S. degree is the equivalent of our M.S. However, their M.S. thesis research is not really comparable to our Ph.D. dissertation. As our students switch from the M.S. to the Ph.D. track, they change from a deductive, analytic, knowledge accumulation mode to one where they are required to be inductive, creative, and innovative, which means individualistic. Our Ph.D. qualifying exams at this point encourage them to question what they have been taught, to challenge authority, their professors.

Not so in Japan. In electronics, the emphasis in Japanese schools and industry is on "how to," not on "why does." Their course background in the basic sciences, chemistry and physics, although good, is not really used to challenge new problems as we try to do in this

country. Rather, their emphasis on specialization, on (derived) engineering concepts and recipes means that they are much better equipped than we are at making the small day-by-day advances in technology that we are now used to seeing from them. Thus, we are not surprised to see them about to put the 256 K RAM chip into production. Remember that they copied our semiconductor science and technology of 10-20 years ago. To get to that stage, we started with physicists and chemists asking "why?" not "how?" We still tend to teach our students from that point of view. Japanese universities and industries, especially managers in R and D establishments, are very concerned about this problem from a long range point of view. They want to make their R&D more innovative. Although it is difficult for them to alter the group consensus mode of making decisions which comes from the monolithic nature of their culture, they are succeeding in introducing new basic science content and courses in the engineering curricula at the universities.

I think it is worth noting that here in the U.S., we are moving in the opposite direction. The association of electronics with the military and with Vietnam, the recession 10 years ago with the resultant loss of job opportunities and monetary rewards, and the requirement of a long and demanding educational route, means that electronics no longer entices the cream of our youth. This, combined with the recent surge of job opportunities in electronics, whereby both industry and government are emphasizing short term commitments, is putting pressure on our universities to produce technicians, to downgrade the Ph.D. and re-emphasize the B.S., to lower the quality of our graduates, and, in particular, to de-emphasize "why" with respect to "how." Thus, Japan and the United States are moving closer.

Students at good Japanese universities must work very hard to get in, and this carries over once they are accepted. They work very hard. (It is not unusual for thesis students to sleep in the laboratory) These habits eventually carry over to industry. Students have no other responsibilities. They tend to marry late, when in their late twenties.

Women in electronics do not seem to exist, neither at the universities nor in industry. This is clearly rooted in their culture. After finishing high school or perhaps even college, they enter the job market for jobs we might consider menial or even degrading. In 10 years they will marry and leave their jobs altogether. In the interim, because the salary spread in Japan is much narrower than it is here, they can live relatively sumptuously, while their male counterparts are struggling hard with little present financial rewards, to establish themselves in a career. Womanpower is therefore an untapped resource in Japan.

The public universities are run by the Ministry of Education. Each laboratory (each professor) writes a lengthy annual report due each year on April 1. (This is a good source of information about the work of the laboratory) At the same time, they apply for research support for the following year. The review process encourages programs of high standards, but very often without the diversity that characterizes our university research programs. Many professors supplement their research program with industry support, contracts which seem to involve consulting agreements as well.

There are a number of fine, prestigious private universities in Japan. Much of their support also comes from the government, especially their research support. During my trip, one of the largest, most prestigious private universities announced that it was returning its government contribution for that year, about a third of its operating budget, as a face-saving measure because of a scandal involving cheating on its entrance exams. Cultural mores in Japan remain rooted very deep.

The managers of industrial R&D centers uniformly criticize the university research and training programs in solid-state electronics. They claim that a good science base is not taught, that the laboratories are not modern with little hands-on experience in modern circuit design and microfabrication techniques, that the universities are organized along archaic lines, and are too independent and refuse to train students for industry. Breakthroughs come from U.S. universities, not from Japanese universities. On further questioning then, it becomes apparent, for example, that they have seen the Sub-Micron National facility at Cornell and use this as the norm to judge their own universities, or that many of the American breakthroughs have come from the physics departments, not from electronic engineering. I do not think they realize the constraints a professor in Japan is under, especially with regard to his research.

First, much of solid-state electronics was lifted intact from the U.S. 20 years ago, without the science base from which it was developed. The professor may have spent a year in this country at that time and duplicated what he saw here when he returned. Second, although the Ministry of Education places great emphasis on science and engineering, it tends not to support work of a long range nature, nor of a basic nature. They look for well-defined goals. They spread the money around uniformly, so that large one-time spending on major pieces of capital equipment is rare. Industrial support is even more confining. Third, I am not convinced that the professor is willing to gamble on such long range projects where the risk of failure is high, and where there are few short-term rewards. However, there are some mavericks who do not fit this mold. They are individuals, anachronisms to their culture. We see them as standing out, different, leaders. In Japan, they are looked upon more as deviants, not necessarily to be admired.

Contrary to my expectations, and juxtaposed against the shining, sophisticated electronic consumer products coming from Japan, I found university research laboratories to be a hodge-podge of the archaic with the ultramodern. Laboratories in the older universities are in drab concrete buildings with unfinished concrete interiors. Where is the simple beauty of nature that the Japanese so admire? The laboratories are small and crowded. The newer schools are housed in buildings that could best be described as California modern, but their laboratories are also small.

There is relatively little fancy modern equipment. Where it exists it stands out: Hall measurements using a ballistic galvanometer next to a state-of-the-art commercial e-beam lithography machine. Most of the equipment is homemade. Students get experience dismantling older equipment and putting it back together in modern guise. In older laboratories, one can read the history of the laboratory in what one sees: start with a simple diffusion-pumped evaporator, add an e-beam hearth to do Si, add dopant sources, add ion beam sources, improve the vacuum, add HEED, add Auger, add a plasma source and now we have ion implantation, or reactive plasma growth and etching of MBE.

In contrast to university solid-state electronics laboratories in this country, I saw much work in Si processing, many silane reactors, but little work either on the circuit side--circuit design and layout and chip fabrication, or on the physics side--few liquid He experiments.

Industrial R&D laboratories primarily hire the M.S. student. They do this by contacting the professor. The department has a committee which collects this information and tries to match offers to students. This is necessary because the student does not initiate the process. Currently, a student will be given two or three offers. The process is not over yet. He must then pass the entrance exam each company gives.

Again, another entrance exam to be passed! Such exams cover many fields, and the students know this. If you become proficient and creative in one field at the expense of other fields, you are in trouble. Thus, again, you are forced to prepare for the same exam, in the same way as all the others, again breeding think-alike clones who are good at arriving at consensus decisions, who are good at taking rapid, but small, steps in technology, but quantum jumps, wild ideas, and individualism is not tolerated. Both industry and universities do worry about this problem, especially now, that Japan has caught up with American electronics technology.

Starting salaries are very similar in all companies, so you do not select your job on that basis. In fact, starting salaries are about the same for a Ph.D. as well, so you do not get a Ph.D. to start at a higher level. You get a Ph.D. because you want to enter academia. However, I met many Ph.D.'s in my visits to industrial laboratories, mostly older people. The reason for this is simple. After 10 years or so of doing research at a company, the worker may apply to any university for the Ph.D. degree. The university sets up a committee to examine the applicant's record, which usually requires the submission of three or four significant papers in refereed journals. If the committee approves, the Ph.D. is granted without any additional work. The university gets nothing for this. This is why Ph.D.'s in industry are always older, and why so many Ph.D.'s exist even though there are so few Ph.D. students at the university. This Ph.D. awarding process is strongly controlled at government universities, but much less so at private universities, which may grant the degree on the basis of little supporting evidence. Hence, the name of the awarding university is just as important as the fact that you have the degree.

Finally, I note something for which I have no explanation. As described below, the electronics industry realizes that VLSI is useless unless appropriate software is on hand. I was told at several industrial R&D laboratories that they have greatly expanded their staffs in the systems and software areas. In one case they went from 200 to 5,000 in two years! And they are all university trained. The question I have then is how the universities were able to turn on this tap so quickly?

THE RESEARCH LABORATORIES OF THE ELECTRONICS INDUSTRY

I visited the R&D laboratories of seven of the dozen or so largest electronics firms in Japan--the other were not working on MBE, yet. They key to the Japanese success in electronics appears to be the availability of large numbers of highly educated workers who can work hard as a group towards a common well-defined goal. To us, their success in semiconductors is the low price and high reliability of state-of-the-art devices. These devices were not invented in Japan. They are logical extensions from existing device technology. The 256 K RAM, is the next logical extension from LSI technology, and the single mode, buried channel, V-groove or meniscus active layer lasers are extensions from the simple, stripe geometry, DH laser. Their strategy is relatively simple: Start with a current device. Set a clearly defined, market acceptable goal to push it one step beyond where it stands at present. Work hard on demonstrating feasibility. Then deploy it rapidly into production, aiming for high volume and high yield (zero defects).

Whereas we push semiconductor technology ahead predominantly to fulfill the needs of the military, the Japanese market for such devices is in consumer and industrial products, a large volume, relatively stable market. The large Japanese companies are integrated vertically, selling consumer and industrial products, as well as semiconductors. Thus, the primary goal of their semiconductor development is for in-house use, with the resultant automatic feedback built in. Fast turnaround times and large volumes allow them to move down the learning curve rapidly.

Their domestic market for consumer products serves as a test market before export, as well as a stable market. The Japanese consumer is now relatively affluent, but, in a crowded country, with small houses on small plots of land, his expression of individualism comes, in part, from the consumer products he buys, e.g., personal computers, VCR's. He is highly educated, so that he can assimilate such advanced products, but also, his sophistication in choosing between competing products leads to strong competition among the manufacturers, and therefore to a better product.

The strength of Japanese innovation is based in large measure on the unique interaction of their people: workers, managers, and government, and this requires clearly visible goals. In the fifties and sixties they copied our science and technology. This was their goal then. More recently, I have seen some of their projections for VLSI technology. They sounded like some IBM projections I saw a few years ago. However, it is clear that they have the capabilities to implement these goals rapidly and efficiently. During the recession and the oil embargo of the early seventies, our semiconductor industry suffered badly. The Japanese industry flourished. They used this opportunity to close the gap between them and us. Electronics was pushed as a means of conserving energy in a country with no native energy resources and export markets were expanded, particularly in the Third World.

The field of semiconductors is now relatively mature. Major breakthroughs are now few and far between. Thus, success comes from the small step by step advancement of the existing state-of-the-art and that is the strength of the Japanese. They are ideally positioned to continue this into the future. There are seven companies now selling 64 K RAMS. All the ready for a VLSI explosion. They talk of dropping a 256 K RAM in every consumer and industrial product they now make. They are working towards expanded consumer markets for VCR's, video disc players, personal computers, and word processors, and towards industrial markets for computers, robots and communications systems. They are very rapidly making their presence felt in the software field. They have become accustomed to rapidly changing technology and products and they accept this as normal. Their companies are large and they can compete successfully among each other or with foreign companies. Of course, they have not yet experienced any serious downturns. Be that as it may, barring any unforeseen breakthroughs in technologies or changing markets, they are ideally situated to dominate the world's semiconductor markets for the foreseeable future.

The introduction of new products with very fast turnaround times is essential to their dominance in the market. Thus, their R&D investment is high, typically 5% of gross sales; on occasion it has gone as high as 20%. (The typical U.S. figure is 1%.) Capital investment in new production facilities is also very high. Apparently, investment capital is readily available at low interest rates.

It is normally acknowledged that the success of Japan Incorporated is due in no small part to the Japanese government. For the semiconductor industry, it is MITI (the Ministry of International Trade and Industry) that plays the central role. Its basic thesis is that expanding technology and technological exports are good for the nation. However, MITI is not a very strong force for the expansion of Japanese technology. It does not rule with an iron hand. It does not really regulate or control industry. Instead it tries to guide, and to provide the nutritive environment in which the individual companies compete. It tries to project and establish long range goals (10-20 years ahead) by arriving at consensus decisions with the managers of the appropriate companies, e.g., three-dimensional VLSI could become important in the 1990s. Then it forms a loose consortium among various interested companies, and with very small grants (only 1% of the R&D budget of NEC comes from the

government) it starts the companies working towards the goal. The work is not closely directed; as long as the work continues in the general area it is alright. MITI guides only by small funding corrections if it thinks the work has strayed too far from the area of interest.

MITI itself is composed of former company managers. Its decisions are made by consultation with committees of company managers. Thus, the goals they establish come from consensus decisions involving both the companies and the government. The companies are then simply encouraged to work towards those general goals. There are no specific final goals or clearly defined device structures. There are no timetables with goals at each stage. The work is relatively open ended. However, remember, that what the Japanese do best is working towards a goal. Thus, the interaction of MITI with industry to help establish goals is very important.

The presence of MITI was evident in every R&D laboratory I visited. In almost every laboratory, there was one man, one machine working on a solar photovoltaic project, which was unrelated to anything else going on. Amorphous or polycrystalline Si, GaAs, InP or various alloys was being grown on glass, steel, etc. by VPE, MOCVD, MBE, plasmas, etc., sometimes duplicating similar work elsewhere, sometimes moving down an apparently blind alley. All this is accepted as part of the program. VLSI and fast GaAs devices are part of such programs, but they are obviously much closer to the immediate goals of the company. VLSI in three dimensions, involving the epitaxial growth of Si/Insulator, insulator/Si, Si/metal (silicides) and metal/Si structures is just beginning. Finally, while I do know that MITI plays a role in arranging borrowing of money under favorable terms, in arranging favorable export agreements and import protectionism, and, generally assisting the electronics industry, I am not sure how all this works.

The new engineer or scientist joins the company R&D laboratory with his M.S. degree in electronics as the cream of the crop of the Japanese university system. Continuing his habits from the university, he will still work hard and for long hours for a salary, considerably less than what he could earn in the U.S., and his salary over the years will not increase as rapidly as it would here. Still, if he is working for one of the large companies, it is basically a job for life. There are many fringe benefits not contained in his salary, not least of which is the tacit assumption that he will probably never be laid off, no matter how bad economic conditions become. (At the smaller companies, mostly subcontractors, this is not true.) Thus, for the worker it is a life time job. From this follows company loyalty, and optimism and faith in the future. From the company point of view this also has advantages. They can invest in his further training and education; they can keep his job flexible and allow him to change; they will make sure that he knows how the company operates and what its goals are. Thus, a new employee may spend a year working in various different, unrelated areas, both to see what the company is all about, and to see where he best fits in.

The R&D scientist or engineers I saw were mostly young, as in the U.S. semiconductor laboratories 20 years ago. There are no technicians. Each staff member does his own experiments. This includes all the tedious, painstaking work normally relegated to a technician in this country. In the laboratory, it is usually one man, one machine (or experiment), but their desks are often in a common office, thus facilitating communication. Group discussions, group decisions-consensus, are the rule, even bringing together people working in different areas. Even those working towards the same goals, but with somewhat different approaches, will talk to each other. In the U.S. they would be competing head-on and communication might not be possible. Life-long employment means that the group is stable, its members get to know each other very well. From this, come easy consensus decisions, team efforts and, above all, pride in the accomplishments of the

group, with individual pride taking a much lower place than it does in our country. An entire group may move to a factory for a while to establish a new production technique.

R&D managers, who usually rise from the ranks imbued with the group spirit and consensus thinking, continue to operate that way. Dr. Kikuchi, director of the Sony Research Center told me that he once tried to reorganize his laboratories in the traditional American method of vertical management, where each manager was responsible for only a small part of the laboratories work, and was relatively independent of other areas. The system broke down when the managers complained that they were not being consulted on problems involving other areas. They felt that they were being left out. Thus, Sony returned to the typical horizontal system. Here, departments are only loosely defined. The key men are those, usually called assistant directors, who have no direct line administrative responsibilities. The move from group to group, a few hours here, a few days there. They are the ones who collect and spread ideas, develop consensus decisions for establishing goals, and it is probably through this type of interaction, that rapid changes in direction become possible.

Once a goal is set, the next step is to start work in parallel on all possible approaches to the goal, even if it is not obvious that a particular approach will work, even if the approach does not follow from a scientific base. This is in direct contrast to the U.S., where work will not start until a careful study shows the best path, each step worked out in some detail and with a good chance of success. Their justification for starting by trying everything at once is, first, they are starting to work on it right away, and second, if a better way emerges, they can alter their approach rapidly. The MITI projects fit into this mold. Each laboratory works on a different approach to a common goal, with little interaction, until one approach begins to look promising.

Even in the R&D laboratory, there is always a great deal of thought given to reliability and quality control. Experiments are performed on expensive production-like equipment designed for reproducibility and control. The equipment is much more elaborate than at university laboratories. Accelerated life test stations are never very far from the research equipment. Their goals are clearly enunciated and they take pride in meeting them.

CONSIDERATION OF CREATIVITY IN JAPAN

Joe Yamamoto

INTRODUCTION

A discussion of the present culture in Japan to weigh the pros and cons of creativity, vis-a-vis culture, is difficult without a historical perspective. Although in China, Korea, and Japan, there are national values and identities, all three share certain common cultural heritages. Among these are the influences of the Chinese which include Confucianism, Buddhism, Taoism, the complex Chinese written language, and customs such as celebrating the New Year in a special culturally syntonic way.

PAST CREATIONS IN ASIA

When one looks at the history of China, Korea, and Japan, there have been monumental contributions towards the history of civilization. Among the contributions of the Chinese are the written language, gunpowder, pasta, printing press, etc. The Chinese influenced the Koreans who continued the inventiveness and developed a very strong traditional culture of their own. For many centuries the Koreans excelled in creativity in the arts which include beautiful celadon pottery. They developed and became Buddhist Koreans who were instrumental in the construction of beautiful temple works of art such as the Sokkuram in Kyongju, Korea. Many classic brass bells were cast centuries ago.

Finally, the Japanese followed the traditions of the Chinese and Koreans with improvements in these areas. It should be noted that the Koreans devised Hangul, a phonetic alphabet, unrelated to the Chinese pictographs. Two hundred years later, the Japanese developed a phonetic alphabet derived from some of the Chinese pictographs which they simplified. In both examples, in Korea and Japan, these inventions made it easier to learn to read and write.

The fact is that in all three nations there has been considerable emphasis on socialization for achievement. That is to say, the parents greatly emphasize educational attainment and long-term objectives such as becoming professionals or leaders in industry, government, etc.

Having just had a very brief look at the history of the Chinese, Koreans, and Japanese, let us turn now to the current issue of the culture of Japan. I believe I have emphasized the fact that the culture has been very much influenced by the Chinese and Koreans as similarly the Japanese have had some impact on the Koreans and Chinese. Rather than to dichotomize the answer into yes, the culture facilitates creativity, or no, the culture stultifies it, I have chosen to look at those strengths which may contribute toward creativity and those weaknesses which may detract.

A first attempt to look at cultural attributes might be the following: A comparison of the values, traditions, and emphasis in American civilization and in Japan.

AMERICAN CIVILIZATION

Individualism

vs

Independence

vs

JAPANESE CIVILIZATION

Familism

Interdependence

Protestant ethics: emphasis on work, science and technology; man's ability to control his environment; religious support of man's endeavors toward economic and material progress	vs	Confucian ethics: loyalty between lord and subordinates; intimacy between father and sons; propriety between husband and wife; order between elder and junior; trust between friends
Present and future orientation	vs	Past, present, and future orientation
Tolerance of differences	vs	Tolerance for similarities
Emphasis on self-fulfill- ment, self-development	vs	Emphasis on interpersonal relationships
Emphasis on individual achievement	vs	Emphasis on group achievement
Emphasis on newness, change	vs	Emphasis on newness and change in the context of tradition

DISCUSSION

What are the consequences then of the differences in the cultures of America and Japan? It is quite apparent that the most dramatic difference is between the individualism in the United States and familism in Japan, with the correlated independency striving in the United States versus interdependency in Japan. This latter is hard for American scientists to understand, but is very understandable to most Asians who grew up in somewhat similar cultures with emphasis upon the past, present, and future. Certainly in Japan as in many of the Asian countries, there is a distinct emphasis on hierarchy so that, for example, when a Japanese worker begins in a corporation, this dates his seniority and so everyone else is either his senior (senpai) or junior (cohai). This determines, not only ones salary, which is increased at annual intervals, but also the likelihood of being promoted into positions of power.

In the United States, especially in California which is in the forefront of America, there is a great tolerance for differences. This is illustrated in the fact that a professor in our Neuropsychiatric Institute (NPI) can be attired in any way he or she pleases. In the Eastern United States there is an emphasis upon more formal attire and demeanor. This traditional behavior is even more emphasized in Japan and the rest of Asia because of the great emphasis upon awareness of social interaction pointed out by Takie Lebra.

Going on to items six, seven, and eight, the emphasis upon the self in America, versus Japanese emphasis on interpersonal relationships, the group (whether family, school, work, or other important group), and the maintenance of traditional values.

Americans may have some difficulty seeing that although the development of Japan, Korea, and the Chinese in Taiwan have given a superficial aura of westernization, this has been within the context of tradition. Examples of this are in Japan fully 70% to 80% of the youth still say that when they get married they would certainly want the approval of their parents. I remember my discussion with a professor in Seoul, where I inquired about his three sons. "Will they have to get your permission?" The professor said, "Yes, of course."

Thus, there is a tremendous emphasis on socialization for achievement, it is always in the context of awareness of interpersonal relationships, interdependency, and the traditional values.

If one hypothesizes that a necessary condition of creativity is to be able to think the "unthinkable," then as can be seen by the contrast between America and Japan, the American emphasis on individualism, tolerance of differences, and emphasis upon individual achievement, newness, change, may facilitate the creative process. There is no question that the American society has fostered the invention of many very important technological instruments which have helped to produce an America with increased productivity, a higher standard of living, and with great emphasis upon "new and improved" products, techniques, instruments, etc.

It would be my hypothesis then that in Japan, as in other Asian nations, there are some obstacles toward the sort of creativity that initiate great changes. However, even though it may be more difficult to think the unthinkable and therefore, make a leaping creative contribution, the emphasis upon improvement of what is known is a form of creativity which should not be ignored and has fueled much of the increased technological improvements in Japan in the past decade. Examples are the use of robots in the manufacturing process. I remember 16 years ago hearing that the Seiko Watch Company had changed to automation, I wondered why this is necessary in a Japan which at that time had relatively inexpensive labor. The answer, of course, lies in the emphasis upon quality control and the production of a product which will endure, be reliable, and trustworthy.

The strength of the Japanese culture lies in the attributes of teamwork, group orientation, interpersonal sensitivity, the willingness to work together towards long-range goals. The entire social structure is based upon the recognition of ones obligations and station in life. There is a system of reciprocal relationships in which the superior relates to the subordinate in specific, hierarchical ways which communicates the different station in life, together with a consideration of the responsibility to assure the needs of the latter. In response, the subordinate communicates the subordinate station and also the obligation to look after the needs of the superior. In this way, the Japanese culture facilitates a sharing of responsibility, work, and the benefits of the productivity of the group.

Because of this sharing of work, responsibility, obligation, and productivity, there is a certain group pride in the product. This, together with the emphasis upon quality control has helped in changing the quality and reputation of Japanese products. From the standpoint of emotional health, this emphasis upon the family, the group, may be positive in that it permits emphasis on "social feelings" (i.e., concern for others) which are a very important part of ones emotional needs. Thus, in contrast to cultures where there are problems related to narcissism, the emphasis upon the group and on interpersonal sensitivity forces a continuing consideration of the needs of others, and ones responsibilities to them.

It is possible that "social feelings" may thus result in a concern for creativity in the service of the group, such motivations may be less prevalent in the American society since the more individualistic considerations are paramount in America. Thus, in addition to the individual gains that a creative individual may reap in Japan, there will be the additional benefits of the social feeling of having advantaged ones group or ones society. It seems quite likely that this will enhance the motivation towards creativity. Thus, the deficit in terms of the ability to think "the unthinkable" may be countered by the advantage of increased motivation due to the social feelings of helping ones group and ones society.

There is the additional attribute of working in the group, that is to say, that there can be a certain "social facilitation of work." In other words, groups may be able to accomplish tasks that may be very difficult for individuals. This has certainly been illustrated by experiments where two or more individuals may be able to accomplish tasks that either individually may have been incapable of completing. Thus, in many ways the fact that groupism may discourage individual creativity can be counterweighed by the ability of groups under certain circumstances to arrive at ideas, concepts, or solutions which are unavailable to individuals per se. It would seem that the final verdict will come in terms of a historical perspective which future scientists will contribute.

In summary, then, it is my hypothesis that the society in Japan, as in most of Asia, fosters an interdependency which may be good for team work, group morale, and the establishment of creativity, and for decisions among the members of a group. This may in some ways hinder the sort of creative leap which may be necessary in inventing a product which has not yet been conceptualized.

INTERNATIONAL MEETINGS IN THE FAR EAST

1982-1986

Compiled by Seikoh Sakiyama

This list will be updated and augmented in future issues of the *Scientific Bulletin*. The assistance of Dr. T. D. Grace, of the Australian Embassy, Tokyo, and Dr. M. J. McNamara, of the New Zealand Embassy, Tokyo, in supplying a list of meetings in their countries is deeply appreciated. Similarly, the assistance of Dr. E. D. Rankin, of the American Embassy, Manila, Dr. J. H. Hubbell, of the NBS, Washington, Dr. F. A. Richards, of the ONR, London, Dr. R. J. Marcus, ONR, Pasadena, the Japan Convention Bureau, Tokyo, and Dr. Paul Naitoh, Naval Health Research Center, San Deigo, in providing schedules of meetings is gratefully acknowledged. Readers are asked to notify us of upcoming international meetings in the Far East which have not yet been included in this report.

1982

1982, continued

Date	Title	Site	For information, contact
July 4-10	The VI International Symposium on Solute-Solute-Solvent Interactions	Osaka, Japan	Professor H. Ohtaki Tokyo Institute of Technology at Nagatsuka Dept. of Electronic Chemistry Nagatsuta, Midori-ku Yokohama 227
July 10-16	The 5th International Congress of Plant Tissue	Yamanashi, Japan	Asst Professor A. Komamine Dept. of Botany Faculty of Science University of Tokyo 7-3-1, Hongo, Bunkyo-ku Tokyo 113
July 11-16	The 7th World Congress on Animal, Plant, and Microbial Toxins	Brisbane, Australia	Dr. Ann M. Caneron 7th WCAPMT Zoology Department University of Queensland St. Lucia, Queensland 4067
July 26-29	The Fourth International Symposium on the Finite Element Methods in Flow Problems	Tokyo, Japan	Dr. M. Kawahara Dept. of Civil Engineering Chuo University Kasuga, Bunkyo-ku Tokyo 112
August 15-21	International Biochemical Congress	Perth, Australia	Australian Academy of Science and International Union of Biochemistry P.O. Box 783, Canberra A.C.T. 2601

1982, continued

Date	Title	Site	For information, contact
August 16-20	The 13th Australian Spectroscopy Conference	Melbourne, Australia	Australian Academy of Science P.O. Box 783, Canberra City A.C.T. 2601
August 16-20	The Fourth International Symposium on Antarctic Earth Sciences	Adelaide, Australia	Dr. R.L. Oliver Department of Geology University of Adelaide Adelaide, S.A. 5001
August 17-20	The 2nd International Kyoto Conference on New Aspects of Organic Chemistry	Kyoto, Japan	Professor Z. Yoshida Dept. of Synthetic Chemistry University of Kyoto Yoshida-Hommachi Sakyo-ku, Kyoto 606
August 18-20	Annual Meeting of the Australian Society for Reproductive Biology	Sydney, Australia	Dr. R.H. Scaramuzzi CSIRO, Division of Animal Production P.O. Box 239, Blacktown N.S.W. 2148
August 22-26	The 7th Asia and Oceania Congress of Endocrinology	Tokyo, Japan	Professor K. Shizume Dept. of Medicine 2 Tokyo Women's Medical College Kawadacho, Shinjuku-ku Tokyo 162
August 22-27	The 4th International Conference on Organic Synthesis (IUPAC)	Tokyo, Japan	Professor T. Mukaiyama Dept. of Chemistry Faculty of Science University of Tokyo 7-3-1, Hongo, Bunkyo-ku Tokyo 113
August 23-27	The Royal Australian Chemical Institute 7th National Convention	Canberra, Australia	Executive Secretary, RACI HQ 191 Royal Parade Parkville, Vic. 3052
August 23-27	The 8th Congress of International Ergonomics Association	Tokyo, Japan	Masamitsu Oshima, Director The Medical Information System Development Center Landick Akasaka Bldg. 2-3-4, Akasaka, Minato-ku Tokyo 107

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Date	Title	Site	For information, contact
August 23-27	The 6th Australian Statistical Conference	Melbourne, Australia	Professor E.J. Williams Dept. of Statistics University of Melbourne Parkville, Vic 3052
August 23-27	The 5th Australian Institute of Physics Congress	Canberra, Australia	Vice President Australian Institute of Physics Royal Military College Duntroon, A.C.T. 2600
August 23-27	The 13th Australian Polymer Symposium	Canberra, Australia	Dr. G. Williams Dept. of Chemical Engineering University of Adelaide G.P.O. Box 498 Adelaide 5001
August 24-26	Chemical Engineering Conference	Sydney, Australia	The Institute of Engineers, Australia 11 National Circuit, Barton, A.C.T. 2600
August 24-26	1982 International Conference on Solid State Devices	Tokyo, Japan	The Japan Society of Applied Physics Kikai Shinko Kaikan 5-8, 3-chome, Shiba koen Minato-ku, Tokyo 105
August 24-27	The 10th Australian Ceramic Conference	Melbourne, Australia	Mr. R.Bowman, CSIRO Division of Building Research P.O. Box 56, Highett Vic 3190
August 25-27	The 2nd Conference on Control Engineering	Newcastle, Australia	The Conference Manager The Institute of Engineers, Australia 11 National Circuit, Barton, A.C.T. 2600
August 25-30	The 7th Sagamore Conference on Charge, Spin, and Momentum Densities	Nikko, Japan	Professor S. Hosoya The Institute for Solid State Physics University of Tokyo 7-22-1, Roppongi Minato-ku, Tokyo 106

1982, continued

Date	Title	Site	For information, contact
August 27-30	The Second International Symposium on Molecular Beam Epitaxy and Related Clean Surface Techniques	Lake Kawaguchi, Japan	Professor R. Ueda Department of Applied Physics School of Science and Engineering Waseda University 4-1, Ohkubo 3-chome Shinjuku-ku, Tokyo 160
August 29-September 4	The 5th International Congress of Pesticide Chemistry, IUPAC	Kyoto, Japan	Rikagaku Kenkyusho (The Institute of Physical and Chemical Research) 2-1 Hirosawa, Wako-shi Saitama 351
August 30-September 1	The Sixth International Symposium on Night- and Shiftwork	Kyoto, Japan	Mr. H. Saito Organizing Committee c/o Institute for Science of Lab 1544 Sugao, Takatsu-ku, Kawasaki, Kanagawa 213
August (tentative)	The 4th International Conference in Australia on Finite Element Methods	Australia (undecided)	Professor L.K. Stevens Dept. of Civil Engineering University of Melbourne Parkville, Vic 3052
September 1-3	1982 Symposium on VLSI (Very Large Scale Integrated Technology)	Kanagawa, Japan	Professor S. Tanaka Dept. of Applied Physics Faculty of Engineering University of Tokyo 3-1, Hongo 7-chome Bunkyo-ku, Tokyo 113
September 6-10	International Conference on Magnetism-1982 (ICM-1982)	Kyoto, Japan	Professor J. Kanamori Faculty of Science Osaka University Toyonaka, Osaka 560
September 6-10	International Conference on Nuclear Physics in the Cyclotron Energy Region	Osaka, Japan	Professor M. Kondo Research Center for Nuclear Physics Osaka University Yamada-kami, Suita-shi Osaka 565
September 13-16	The 6th International Symposium on Contamination Control	Tokyo, Japan	Japan Air Cleaning Association 6-7-5, Soto-Kanda Chiyoda-ku, Tokyo 101

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1982, continued

Date	Title	Site	For information, contact
September 13-16	The Sixth International Conference on Software Engineering	Tokyo, Japan	Information Processing Society of Japan Kikaishinko Building 3-5-8, Shiba-koen Minato-ku, Tokyo 105
October 3-6	The 3rd International Dental Congress on Modern Pain Control	Tokyo, Japan	Japan Convention Service, Inc. Nippon Press Center 8F 2-2-1, Uchisaiwai-cho Chiyoda-ku, Tokyo 100
October 20-22	The International Conference on Productivity and Quality Improvement-Study of Actual Cases	Tokyo, Japan	Japan Management Association 1-22, Shiba-koen 3-chome Minato-ku, Tokyo 105
October 24-29	The Second International Conference on Stability of Ships and Ocean Vehicles	Tokyo, Japan	Professor S. Motora The Society of Naval Architects of Japan 15-16, Toranomon 1-chome Minato-ku, Tokyo 105
October 25-29	The 14th Plenary Meeting of 150 Technical Committee 17-Steel	Tokyo, Japan	The Iron and Steel Institute of Japan 10F Nippon Bldg., 7-1 Otemachi 2-chome Chiyoda-ku, Tokyo 100
November 6-9	Electric Energy Power Electronics Conference	Adelaide, Australia	The Conference Manager The Institute of Engineers, Australia 11 National Circuit Barton, A.C.T. 2600
November 17-19	The 3rd JIM (Japan Institute of Metals) International Symposium	Japan (undecided)	The Japan Institute of Metals Aza Aoba, Aramaki Sendai-shi, Miyagi 980
November	Pan Pacific Synfuels Conference	Tokyo, Japan	Japan Petroleum Institute Chiyoda-Seimei Bldg. 27-12, Nishi-Ikebukuro 3-chome, Toshima-ku Tokyo 117
November 26-December 2	The 7th International Conference on Vacuum Metallurgy	Tokyo, Japan	The Iron and Steel Institute of Japan Keidanren Kaikan 1-9-4, Otemachi Chiyoda-ku, Tokyo 100

1982, continued

Date	Title	Site	For information, contact
December 6-8	TENCON 82 VLSI Microcomputer Today and Tomorrow	Hong Kong	Dr. Ronnie K.L. Poon TENCON 82 Chinese University of Hong Kong New Territories, Hong Kong
December 6-10	Chemrawn II	Manila, Philippines	New Frontiers Coordinating Office International Food and Policy Research Institute 1776 Massachusetts Ave. N.W. Washington, D.C. 20036
Undecided	International Conference on Mass Spectroscopy	Hawaii, U.S.A.	Professor T. Tsuchiya Basic Science Lecture Room Chiba Institute of Technology 1-17-2, Tsudanuma Narashino, Chiba 275
Undecided	International Rehabili- tation Medicine Associa- tion Fourth World Congress	Sydney, Australia	Professor G.G. Burniston Dept. of Rehabilitation Medicine Prince Henry Hospital Little Bay, N.S.W. 2036
Undecided	Workshop on Marine Microbiology	Seoul, Korea	Korea Ocean Research and Development Institute P.O.Box 17, Yang-Jae Seoul, Korea

1983

Date	Title	Site	For information, contact
February 1-11	The 15th Pacific Science Congress	Dunedin, New Zealand	University of Otago P.O. Box 6063 Dunedin, New Zealand
March (tentative)	Conference on Coastal Engineering	Queensland, Australia	Conference Manager The Institution of Engineers, Australia 11 National Circuit Barton, A.C.T. 2600

1982, continued

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September 13-16	The Sixth International Conference on Software Engineering	Tokyo, Japan	Information Processing Society of Japan Kikaishinko Building 3-5-8, Shiba-koen Minato-ku, Tokyo 105
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1983, continued

Date	Title	Site	For information, contact
May (tentative)	The 36th Annual Metals Congress	Pt. Kembla, Australia	Australian Institute of Metals P.O. Box 1144, Wollongong N.S.W. 2500
May 16-20	The 5th National School and Conference on X-Ray Analysis	Melbourne, Australia	Dr. R. A. Coyle X-Ray Analytical Association, New South Wales Institution of Technology P.O. Box 90, Parkville Vic 3052
May 16-20 (tentative)	Annual Scientific Meeting of the Australian Society for Microbiology	Brisbane, Australia	The National Secretary Australian Society for Microbiology Inc. 191 Royal Parade Parkville, Vic 3052
August 1-7	International Association for Dental Research	Sydney, Australia	Mr. Scott Gotjamans Dept. of Pathology Perth Medical Center Verdon Street Nedlands, W.A. 6009
August 17-24	The 4th International Congress of Plant Pathology	Melbourne, Australia	Mr. B. Price Victorian Plant Research Institute Dept. of Agriculture Victoria, Swan Street Burnley, Vic 3121
August 21-27	The 5th International Congress of Immunology	Kyoto, Japan	The Japanese Society for Immunology Institute of Virus Research Kyoto University Kawaracho, Shogoin Sakyo-ku, Kyoto 606
August 27	Symposium Commemorating the 100th Anniversary of the Mount Krakatau Eruption	Jakarta, Indonesia	Dr. Didin Sastrapradja Indonesian Institute of Sciences LIPI, JL Teuku Chik Ditiro 43 Jakarta
August 27-31	The 25th International Geographical Congress	Sydney, Australia	Australian Academy of Science P.O. Box 783 Canberra, A.C.T. 2601

1983, continued

Date	Title	Site	For information, contact
August 26-September 2	The 18th International Ethological Conference	Brisbane, Australia	Professor E. McBride Dept. of Psychology University of Queensland St Lucia, Qld 4067
August 28-September	The 29th International Congress of Physiology	Sydney, Australia	Australian Academy of Science P.O. Box 783, Canberra A.C.T. 2601
August 28-September 2	The 29th International Congress of Physiology	Sydney, Australia	Australian Academy of Science P.O.Box 783, Canberra A.C.T. 2601
August 28-September 3	The 3rd International Mycological Congress (IMC 3)	Tokyo, Japan	Professor K. Tsubaki Institute of Biological Sciences The University of Tsukuba Sakura-mura, Ibaraki 305
August (tentative)	International Solar Energy Congress	Perth, Australia	Mr. P. Driver Honorary Secretary P.O. Box 123 Nedlands, W.A. 6009
August (tentative)	Computers in Engineering	Australia (undecided)	The Conference Manager The Institution of Engineers, Australia 11 National Circuit Barton, A.C.T. 2600
August (tentative)	Hydraulics and Fluid Mechanics Conference	Newcastle, Australia	The Conference Manager The Institution of Engineers, Australia 11 National Circuit Barton, A.C.T. 2600
September 19-23	The 12th World Energy Conference	New Delhi, India	Dr. R.J. Ramdebough 1620 Eye Street Suite 808 Washington, D.C. 20008
September 22-26	The 4th Asian and Australian Conference ISRT (International Society of Radiologic Technologists)	Tokyo, Japan	Mr. Lucky Morimoto International Department The Japan Association of Radiologic Technologists 26-7, Shinkawa 1-chome Chuo-ku, Tokyo 104

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Date	Title	Site	For information, contact
October 2-5	The 3rd International Display Research Conference	Kobe, Japan	Japan Convention Services, Inc. Nippon Press Center 8F. 2-1, Uchisaiwai-cho 2-chome, Chiyoda-ku Tokyo 100
October (tentative)	The 8th International Conference on Calcium Regulating Hormone	Kobe, Japan (tentative)	Professor T. Fujita 3rd Division Dept. of Medicine School of Medicine Kobe University 7-13, Kusunoki-cho Ikuta-ku, Kobe 650
October 29- November 3	The 71st FDI Annual World Dental Congress (Federation Dentaire Internationale)	Tokyo, Japan	Japan Dental Association (Japanese Association for Dental Science) 4-1-20, Kudan-kita Chiyoda-ku, Tokyo 102
November (tentative)	Conference on Micro-processors	Australia (undecided)	The Conference Manager The Institute of Engineers, Australia 11 National Circuit Barton, A.C.T. 2600
November (tentative)	Metal Structures Conference	Brisbane, Australia	The Conference Manager The Institution of Engineers, Australia 11 National Circuit Barton, A.C.T. 2600
December (tentative)	The 12th International Laser Radar Conference	Melbourne, Australia	Dr. C. Platt, CSIRO Division of Atmospheric Physics P.O. Box 77, Mordialloc Vic 3195
Undecided	The 13th International Congress of Chemotherapy	Melbourne, Australia	Dr. B. Stratford St. Vincent's Hospital 59 Victoria Parade Fitzroy, Vic 3065

1984

Date	Title	Site	For information, contact
May (tentative)	5th International Soils Expansion Conference	Adelaide, Australia	The Conference Manager The Institution of Engineers, Australia 11 National Circuit Barton, A.C.T. 2600
August 24-September 1	The 3rd International Congress on Cell Biology	Kyoto or Kobe, Japan	Japan Society for Cell Biology Shigei Medical Research Institute 2117 Yamada Okayama 701-02

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Date	Title	Site	For information, contact
August (tentative)	International Association Hydraulic Resources Conference	Melbourne, Australia	The Conference Manager The Institution of Engineers, Australia 11 National Circuit Barton, A.C.T. 2600
October 15-18	International Rubber Conference	Kyoto, Japan (tentative)	The Society of Rubber Industry, Japan Tobu Bldg., 1-5-26 Motoakasaka, Minato-ku Tokyo 107

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Date	Title	Site	For information, contact
(Tentative)	International Microbiological Congress	Perth, Australia	Australian Academy of Science P.O. Box 783, Canberra A.C.T. 2601
May 11-17	Congress of the International Society of Haematology and the International Society of Blood Transfusions	Sydney, Australia	Dr. I. Cooper, President Haematology Society of Australia Cancer Institute 481 Little Lonsdale Street, Melbourne Vic 3001

NOTICE

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